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The Two-Stage Current Transformer

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This paper presents a brief discussion of the current transformer as used with measuring and controlling apparatus with special reference to the degree of accuracy which can be attained in the ratio and phase angle. A new type of current transformer is then described, in which it is possible to secure much higher accuracy with a given amount of iron and copper in the transformer. In this new device the transformation is effected in two stages, the first yielding in the usual way a secondary current which is approximately correct in magnitude and phase, and the second yielding an auxiliary corrective current which, when combined with the first secondary current, gives a resultant current which very closely approximates to the secondary current which would be furnished by an ideal current transformer having no errors. The two currents may easily be combined by having two like windings in the devices operated, one for the main and one for the auxiliary secondary current.

The mathematical theory of the two-stage current transformer is developed and applied. Experimental curves are given to compare the performance of the new transformer with that of an ordinary simple current transformer of good average performance. The effect of mutual inductance between the external secondary circuits is discussed, and some of the special advantages of the new transformer are given.

The Simple Current Transformer

THE term "current transformer" as ordinarily used refers to a transformer used to deliver to electrical measuring and controlling devices a definite fraction of the line current. It consists essentially of a core of magnetic material on which are wound two coils, one of which, usually of a few turns of large wire, is connected in series with the high-voltage circuit, while the other coil (usually of a greater number of turns of smaller wire) supplies a secondary induced current which operates the measuring and controlling devices in the secondary circuit. The impedance of the external secondary circuit is properly referred to as the secondary burden.

In order that a secondary current may be induced, a certain component of the primary current must be used to produce the necessary magnetization, and to supply the core loss. The core being of iron it is readily appreciated that this component of current varies with (1) secondary burden, (2) frequency, (3) magnitude of the secondary current. Because this component does not vary directly with the secondary current, the ratio of the two currents varies with any changes in the above three factors occurring either separately or jointly. Also, the electrical phase difference between the primary current and the secondary current, which would be exactly 180 deg. in an ideal transformer, departs from 180 deg. by a small angle, the "phase angle," which varies with each of the three causes mentioned as affecting the ratio of currents. For the accurate operation of electrical measuring apparatus, especially wattmeters and watt-hour meters, it is necessary that the ratio of primary current to secondary current should always be constant in a fixed ratio and that the departure from the 180 deg. phase relation should be negligible. This should be true for all ordinary conditions of secondary burden, primary current and frequency. Changes in ratio affect the readings of instruments at all power factors while phase angles cause errors which greatly increase as the power factor is lowered. For example, in using a polyphase watt-hour meter for measuring the energy delivered over a three-phase system, a variation of 1 per cent in the ratio causes an error of 1 per cent in the registration, irrespective of the power factor. When the system is at 86.6 per cent or 50 per cent power factor, a phase angle of 20 minutes will cause errors of 0.3 per cent and 1.0 per cent respectively in the registration of the meter. While such errors in ratio and phase are known to exist, their effect upon the accuracy of the instruments to which they are connected is not always appreciated. In the past and even at the present day, many central-station men consider a current transformer as of absolute ratio and zero phase angle.

Besides the conditions already spoken of as affecting the ratio and phase angle of the ordinary current transformer, there is the question as to the magnetization of the core brought about during moments of opening and closing of the primary circuit or accidental opening of the secondary under load.

Voltage ("potential") transformers are inherently capable of a very much better performance than current transformers, especially as regards phase angle. The induction watt-hour meter has also been brought to a high state of development, and its performance on inductive and non-inductive loads is readily controlled by the user through the three standard adjustments (light-load, full-load, phase). The current transformer has lagged in development behind the other two essential elements of metering equipment. The only way to improve it radically, with the methods of construction commonly employed, is to use iron of magnetic qualities much superior to anything now commercially available. It is the purpose of this paper to show how the transformation of current for metering purposes can be brought up to an accuracy at least as high as that of the other component functions, by means of a device which we have called a "two-stage" current transformer.

To be presented at the A. I. E. E. Annual Convention, Niagara Falls, Ontario, June 26-30, 1922.

The two-stage current transformer (shown diagrammatically as two distinct transformers in Fig. 1) inherently and automatically effects a correction of current ratio and phase angle between primary and secondary currents to a high degree of accuracy and within wide limits of secondary burden. This is effected in a manner which may be called a "multi-

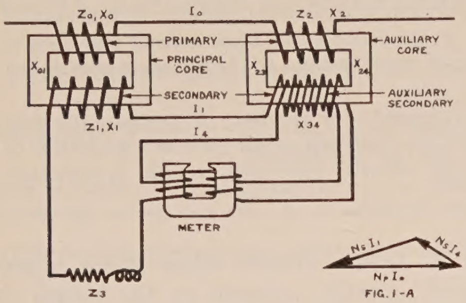

Fig. 1—Elementary Diagram of Electric and Magnetic Circuits of Two-Stage Current Transformer shown as Two Separate Transformers

stage" transformation in which one transformer (the one at the left in Fig. 1) is used to effect the transformation in the ordinary way, yielding a current which is approximately correct as to magnitude and phase. The primary current and this secondary current are then passed through two windings of the second current transformer in which the ratio of secondary turns to primary turns is equal to the desired ratio of primary current to secondary current, the two currents being sent through their respective windings in such a way that their magnetizing effects upon the core (in ampere-turns) tend to oppose each other. (This exact ratio of turns is in contrast to the fact that in ordinary current transformers as now constructed, in order to secure approximately the desired ratio, one or more turns of the secondary winding must be omitted from the number which would be required by an ideal transformer). This second current transformer is provided with another winding called the auxiliary secondary, having very approximately the same number of turns as the principal secondary winding.

It will be evident that if the first transformer is operating under conditions such that the secondary current happens to be exactly correct in magnitude and phase, the ampere-turns of the two windings of the second transformer will annul each other at every moment, and will produce no resultant magnetization in the core of the second transformer and as a result no current will flow in the auxiliary secondary winding.

If, however, as is usually the case in practise, the secondary current produced by the first transformer deviates from the desired ideal value in magnitude or phase angle, or in both, this current and the primary current flowing in opposite directions around the core of the second transformer produce a resultant magnetizing force which acts upon this core. If the auxiliary secondary be now connected to an external circuit, a current will flow which will tend to reduce the flux in the auxiliary core to zero. Under suitable conditions this auxiliary secondary current closely approximates in magnitude and phase to the current which must be vectorially added to the principal secondary current to produce a current such as would be given by an ideal transformer of exact ratio and zero phase angle.

The relations involved may be seen from the vector diagrams of Fig. 2, in which (a) is a simplified diagram of the action of an ordinary current transformer. $O\,F$ represents the direction of the flux in the core, $O\,E_1$ that of the induced secondary e. m. f.; their magnitudes are immaterial for the present discussion. With the usual case of a secondary circuit having resistance and inductance, the secondary current $O\,I_1$ will lag behind $O\,E_1$, and if the secondary coil has one turn, $O\,I_1$ may also represent the secondary ampere-turns. $O\,A$ is drawn of length equal to $O\,I_1$ and 180 deg. away from it, and represents the component of the primary ampere-turns which balances the secondary ampere-turns. To produce the flux and supply the core losses a magnetizing current I_m must flow through the one-turn primary, and I_m shows the magnitude and direction of this current and its magnetizing ampere-turns. Combining $O\,A$ and $O\,I_m$, we get the vector $O\,I_0$, which represents the primary current and its ampere-turns. It may be seen that since $O\,A$ is shorter than $O\,I_0$, I_1 is smaller than the desired value. (In practise, this is usually corrected, for any given set of conditions, by

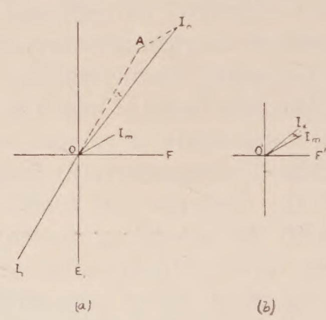

Fig. 2—Vector Relations of the Two-Stage Current Transformer

"dropping secondary turns"; that is, by making their number slightly less than the number required by an ideal transformer. However, for any other set of conditions, the current I_m will in general not change in such proportion to the other currents as to keep the ratio at the desired value.) Also, since $O\,A$ leads $O\,I_0$ by the angle α, the secondary current has a phase error ("phase angle") of this amount.

If we pass $O\,I_0$ and $O\,I_1$ through one-turn windings surrounding another core in such a way that their magnetizing effects are substantially in opposition, their resultant magnetizing force will be equal to $O\,I_m$. These two opposing windings may thus be regarded as equivalent to a one-turn primary winding traversed

by the current I_m. Then in a third one-turn closed-circuit winding around this core (see Fig. 2 (b)) the current I_4 will be induced. It is evident that if this

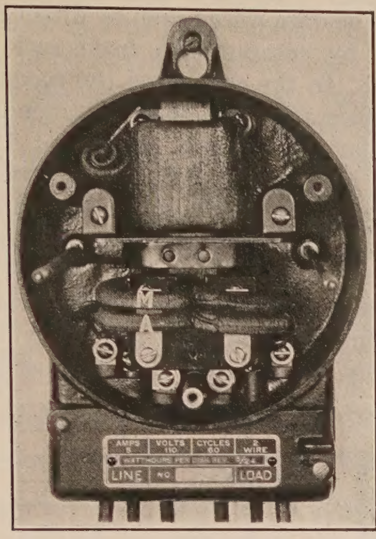

FIG. 3—MOTOR ELEMENT OF WATT-HOUR METER, SHOWING THE TWO CURRENT WINDINGS REQUIRED FOR USE WITH THE TWO-STAGE CURRENT TRANSFORMER

current be vectorially added to $O\,A$ of Fig. 2 (a) the resulting current will be very much closer to $O\,I_0$ in magnitude and phase than is $O\,A$.

The current from the auxiliary secondary may be readily utilized by providing the meter (or other de-

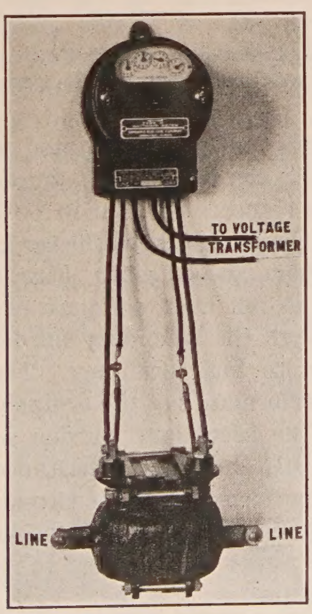

FIG. 4—TWO-STAGE CURRENT TRANSFORMER CONNECTED TO WATT-HOUR METER

vices) with two identical current windings connected respectively to the main and auxiliary secondary circuits, as shown in Figs. 1 and 3. Under such conditions the total ampere-turns in the windings of each instrument so connected to the transformer system will be for all practical purposes exactly equal to the ampere-turns derived from an ideal transformer. The mathematical treatment of the electric and magnetic network involved is given in the appendix to this paper.

Instead of the two physically distinct transformers shown diagrammatically in Fig. 1, it is more convenient to use a single primary winding and a single secondary winding encircling both cores, with the auxiliary secondary winding and a few turns of the main secondary winding surrounding the auxiliary core only.[1] This method of construction produces a two-stage transformer which is physically a single compact unit (see Fig. 4), which shows such a transformer connected to a watt-hour meter. The method of linking the electric and magnetic circuits is shown diagrammatically in Fig. 5, in which the numbers 1, 2, 3 represent the primary winding, the main secondary winding, and the auxiliary secondary winding respectively.

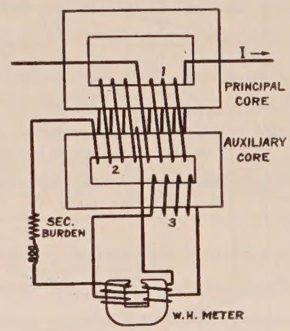

FIG. 5—ELECTRIC AND MAGNETIC CIRCUITS OF TWO-STAGE CURRENT TRANSFORMER MADE AS A STRUCTURAL UNIT

COMPARATIVE PERFORMANCE

Without going into details concerning the causes limiting the accuracy of current transformers having simple secondary windings, it is sufficient to recognize that a higher degree of accuracy in current transformers is desirable in order to bring up the accuracy of the readings of the meters and indication of the instruments which they operate. Let us consider the effect of such errors when the secondary is connected to a watt-hour meter which, for the purpose of this discussion, is assumed to be correct for all loads and power factors within the limits considered. If the meter were connected directly to the line the speed would be proportional to

$$S = E\,I \cos \theta$$

and if we assume next that a current transformer of nominal 1:1 ratio is interposed we would have the speed proportional to

$$S' = \frac{E\,I}{R} \cos (\theta - \alpha)$$

where R is the value, as taken from the calibration curve of the transformer, of the quotient, true ratio divided

1. This construction was suggested by Dr. F. B. Silsbee.

by marked ratio, and α is the small angle (the "phase angle") by which the reversed secondary current leads the primary current.

When operating at unity power factor the term cos $(\theta - \alpha)$ is almost exactly equal to unity, so that the per cent registration of the meter will be almost inversely proportional to R.

As the power factor decreases the effect of α is felt more and more. Since for inductive loads the value of θ is positive there will be a tendency for the meter to run faster as the power factor is lowered. As the load is lowered the values of both R and α increase and in

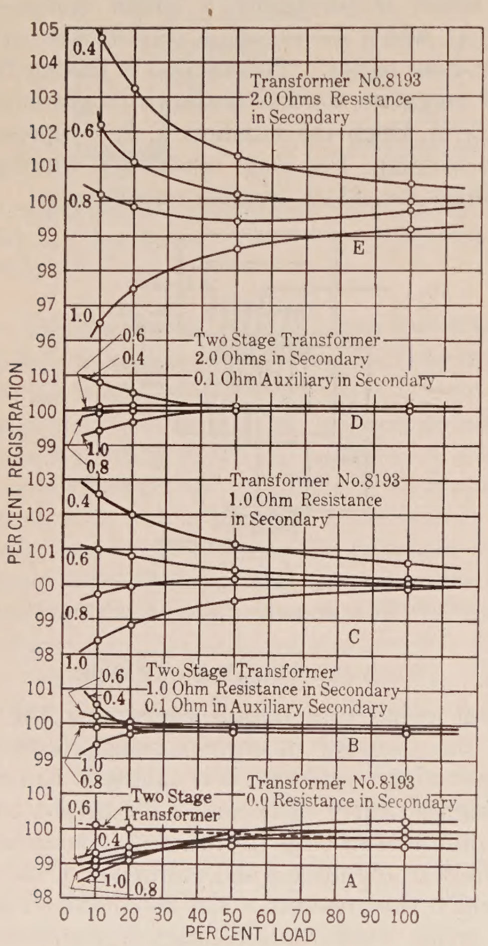

FIG. 6—COMPARATIVE PERFORMANCE OF SIMPLE CURRENT TRANSFORMER AND TWO-STAGE CURRENT TRANSFORMER

general there is a slight tendency for one to compensate the other, yet in most cases the meter will actually exhibit an increased per cent registration on inductive loads. For leading power factors the opposite is true and as the power factor is lowered the meter becomes slower and slower.

Fig. 6C shows this characteristic on inductive loads very clearly. The data as plotted show the degree to which the accuracy of a meter is affected when connected to a line through a modern simple current transformer. This transformer exhibits a good average performance. Transformers of considerably lower accuracy are in service and some of heavier modern designs show a higher accuracy. The curves show the per cent registration of the meter for various loads and at power factors as indicated. Without the transformer the per cent registration would in each case have been 100. The data were taken by direct measurement rather than by computation from ratio and phase-angle curves. In the case cited the secondary burden was 1 ohm resistance plus the resistance of the meter. This particular transformer had about 1200 ampere-turns at full load in the primary. A two-stage transformer was built having about the same amount of iron in its structure but using only one-half the number of ampere-turns. Data were taken on this transformer when connected to a meter and with various values of secondary burden. For zero secondary burden there was practically no deviation from 100 per cent registra-

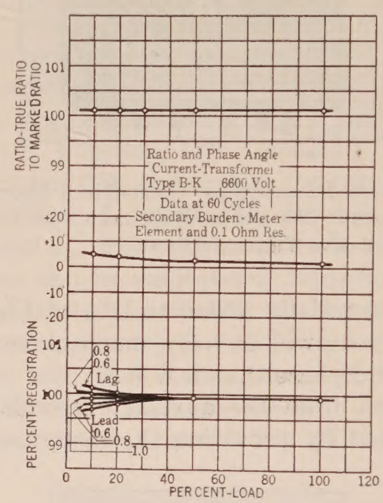

FIG. 7—RATIO, PHASE-ANGLE AND PERFORMANCE CURVES OF TWO-STAGE CURRENT TRANSFORMER

tion for all loads and power factors. Figs. 6B and 6D show the results using secondary burdens of one ohm and two ohms respectively and in both cases there is practically no deviation from 100 per cent registration for all loads above 20 per cent. Figs. 6C and 6E show results which do not even compare favorably with A, B and D, although the secondary burden in case C was very favorable to high accuracy. Fig. 6A shows in full lines the performance of the ordinary current transformer when the secondary burden is only a meter element and 0.1 ohm lead resistance. The dotted line shows the performance of the two-stage transformer under the same conditions. For the latter the curves for the various power factors were so nearly coincident that they are shown as one line.

Fig. 7 shows the conventional ratio and phase-angle curves for the two-stage current transformer with a secondary burden consisting of a watt-hour meter and 0.1 ohm resistance. The lower set of curves, like those of Fig. 6, shows the performance as a function of both ratio and phase-angle.

The above data show the great utility of the two-stage transformer in obtaining the highest degree of

accuracy in electric metering when the use of a current transformer becomes necessary. When used on switchboards the auxiliary secondary need be connected only to the wattmeters and watt-hour meters, since in general an error of 1 to 2 per cent in the indications of ammeters is of no serious consequence.

Watt-hour meters operated from two-stage current transformers need not be calibrated to compensate for inaccuracies in the transformers themselves, since the main secondary and the auxiliary secondary together provide an effective current which is at all times in the proper phase with and ratio to the primary current. This condition is practically independent of any change of secondary burden, frequency, or aging effects in the main core, and should the main secondary become open-circuited the auxiliary secondary will still provide current in approximately the proper ratio.

Effect of External Mutual Inductance

In general the introduction of the auxiliary corrective current into any device means that the main secondary and auxiliary secondary circuits are magnetically coupled outside the transformer. This condition results in the introduction of e. m. fs. into the auxiliary secondary circuit in addition to those generated within the auxiliary secondary coil itself. Such e. m. fs. may become harmful to the successful operation of the transformer if they become sufficiently large. In order to show this effect an experiment was made on a two-stage transformer, as follows: The burden in both main secondary and auxiliary secondary circuits was approximately 0.25 ohm, and 0.79 mh. inductance. The constants of the transformer were first determined with the above secondary burdens and the test repeated using a mutual inductance of 0.21 mh. to couple magnetically the secondary and auxiliary secondary outside the transformer. The tests were made at 60 cycles.

The following table shows the change in constants for the condition with and without mutual inductance:

Without Mutual Inductance					
Per Cent Load....	10	20	40	60	100
Ratio............	1.0017	1.0012	1.0010	1.0010	1.0010
Phase Angle......	5.5′	3.5′	1.5′	0.7′	−0.7′
With Mutual Inductance					
Ratio............	1.016	1.014	1.011	1.010	1.007
Phase Angle......	5.2′	2.0′	0.0′	−3.5′	−5.6′

The above figures show that the introduction of mutual inductance between the main secondary and auxiliary secondary circuits outside the transformer is at least harmful to the ratio of the transformer. It should be noted, however, that the mutual inductance used in the above experiment was about four times as great as that between the two current windings of a watt-hour meter. Furthermore, it is a simple matter to provide an external corrective mutual inductance of equal numerical value but of opposite sign, thus canceling the mutual induction taking place in the meter. This device would be a small laminated core with two windings.

The usual practise of keeping the secondary burden as low as possible should be adhered to in the case of the auxiliary secondary, and the corrective current should be applied only to apparatus where it is required from the standpoint of accuracy.

Some Features of Design

From a practical standpoint it is desirable to make the mutual reactances between primary and auxiliary secondary and between main secondary and auxiliary secondary the same and to arrange the coils so that both of these reactances will vary in the same ratio. This will not always be an easy matter when designing current transformers of high-voltage type, but in a laboratory standard transformer where the insulation between primary and secondary can be reduced to a minimum the problem is less difficult. By breaking up the primary and secondary into a number of sections and interleaving the sections on the core some very remarkable characteristics can be obtained. For example, a two-stage transformer of this type was built which had the primary and secondary built in two sections each and placed on the core in the following order: *P- S- P- S*; ampere-turns at full load, about 900.

The following table shows the characteristics of this transformer for 0.1 ohm resistance in the main secondary and auxiliary secondary circuits.

Per Cent Load....	10	20	30	60	100
Ratio............	1.0005	1.0005	1.0002	1.0002	1.0001
Phase Angle......	2.0′	1.0′	0.5′	0.0′	0.0′

For the commercial testing of instrument transformers such a transformer could be considered as having a fixed ratio and negligible phase angle.

Testing Two-Stage Current Transformers

Almost any of the methods now in use for determining the constants of current transformers can, with slight modification, be applied to the two-stage current transformer.

The Agnew watt-hour meter method[2] will be of particular interest to the laboratory of limited facilities, since it gives results which are sufficiently accurate for all commercial purposes and requires no instruments or apparatus of precision except a current transformer whose constants are known. When testing a transformer of one-to-one ratio even this special transformer is not necessary. The ratio and phase angle as determined by any one of these methods will be termed the "effective" ratio and phase angle since they are determined from the vector sum of two currents.

Fig. 8 shows the arrangement for testing a one-to-one ratio two-stage current transformer. Two watt-hour

2. Agnew, Watt-hour Meter Method of Testing Instrument Transformers, Scientific Paper of the Bureau of Standards No. 233, 1914; Craighead and Weller, *General Electric Review*, Vol. 24, p. 642, 1921.

meters a and b are each equipped with two sets of series coils having the same number of turns as a standard five-ampere coil. Each disk is marked in hundredths of a revolution. The potential coils are connected in parallel to a source of e. m. f. of the same frequency as that which supplies current to the primary of the current transformer and arrangements should be made whereby the phase relations between the main

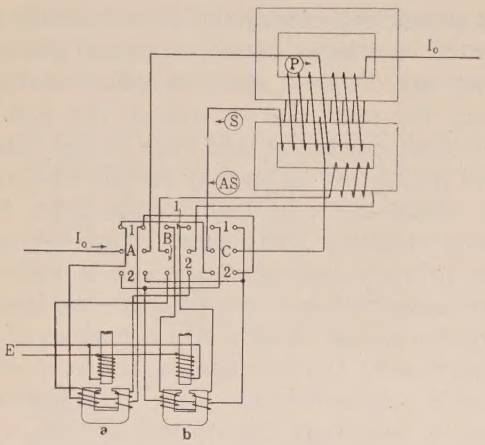

Fig. 8—Diagram of Connections for Agnew Two-Watt-Hour-Meter Method of Testing a 1:1 Ratio Two-Stage Current Transformer

current I_0 and applied e. m. f. E can be altered. It is not necessary that either of the watt-hour meters be in correct adjustment on unity power factor since it is shown that the constants of the two watt-hour meters do not enter into the computations. In many cases, however, the computations are somewhat lessened if the two meters are kept in rather close agreement as regards their constants.

When taking readings at low power factors in order to determine the phase angle it is desirable that the meters be in agreement as regards the angle by which the shunt-field flux lags behind the voltage. It is not necessary that the flux from each potential pole be exactly 90 deg. behind the voltage, but it is desirable that the angle be the same in both. For this reason it has been found desirable to adjust the meters to agreement at unity and at some low power factor; say 20 per cent.

Three double-pole double-throw switches are provided as shown. By throwing the switches first in the position $A_1 B_1 C_1$ meter a is in the primary of the transformer with one of the series coils disconnected while meter b has its windings connected to the secondary and auxiliary secondary respectively of the two-stage transformer. By throwing the switches into the position $A_2 B_2 C_2$ the relative position of the meters is interchanged.

If when the switches are in the position $A_1 B_1 C_1$ we designate by a_1 and b_2 the revolutions recorded on the meters a and b in a given time, and by a_2 and b_1 the revolutions recorded for the two meters a and b when the switches are in the position $A_2 B_2 C_2$, we have the ratio of the transformer

$$R = \sqrt{\frac{a_1 b_1}{a_2 b_2}} \tag{1}$$

if the applied e. m. f. E is in phase with the current I_0.

If the applied e. m. f. is not in phase with the current the quantity under the radical may be termed R', the *apparent ratio* of the transformer, since it is dependent not only upon the effective ratio of the currents but upon the phase angle as well.

From the standpoint of computations it is desirable to make b_1 and b_2 the same, in which case, neglecting terms of second and higher orders, we have

$$R = \sqrt{a_1/a_2} = 1 + \frac{a_1 - a_2}{2\,a_2} \tag{2}$$

When taken at power factors other than unity $1/R' \times 100$ would be the per cent registration which a meter would exhibit when placed in the secondary circuit of the current transformer if it were correct when placed in the primary circuit. Such data would be of particular interest to the practical meterman who desires to know the effect of both ratio and phase angle upon the accuracy of the meter. The curves shown in Fig. 6 are plotted on this basis.

Phase angles are determined by taking readings at both unity and low power factor for the same volt-

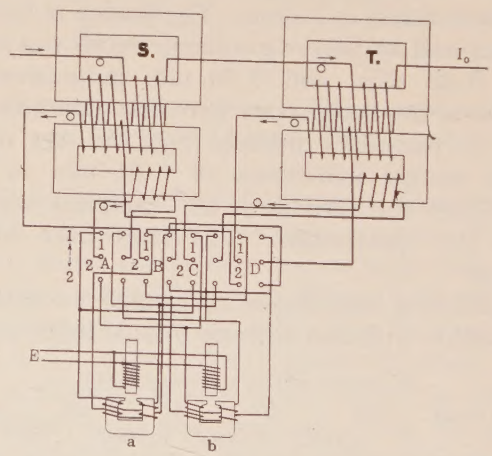

Fig. 9—Diagram of Connections for Agnew Two-Watt-Hour-Meter Method of Testing Two-Stage Current Transformers of Ratio other than Unity

ampere load, using a wattmeter, voltmeter and ammeter to determine the power factor as regards the primary current and applied voltage E. For this case we denote by a_1', a_2', b_1', b_2', the readings corresponding to a_1, a_2, b_1, b_2 in the test at unity power factor. Upon making $b_2' = b_1'$ we have the phase angle

$$\alpha = \tan^{-1}\left[\frac{1}{\tan\theta}(1 - R/R')\right] \tag{3}$$

where $R' = \sqrt{a_1'/a_2'}$ is the apparent ratio at the low

power factor and R is the ratio at unity power factor while θ is the angle between E and I_0.

This formula gives the phase angle in radians. For practical purposes, since the angle is small, we may take the angle as equal to the tangent. Doing this and multiplying by 3438 to reduce to minutes, we have

$$\alpha = \frac{3438}{\tan\theta}\,(1 - R/R')\ \text{(minutes)} \qquad (4)$$

Fig. 9 shows the arrangement for testing a two-stage current transformer whose nominal ratio is different from unity. The transformer S is used as the standard and may be of either the two-stage or simple type. If of the simple type there will be no auxiliary secondary connections from this transformer to the switch as shown. If we let

R_1 = ratio of the standard transformer S
α_1 = phase angle of the standard transformer S
R_2 = ratio of the two-stage transformer B
α_2 = phase angle of the two-stage transformer B

then with the same meaning attached to the a and b symbols as before

$$R_2 = R_1\sqrt{a_1/a_2} = R_1\left(1 + \frac{a_1 - a_2}{2\,a_2}\right) \qquad (5)$$

$$\alpha_2 = \tan^{-1}\left[\frac{1}{\tan\theta}\left(1 - \frac{R_2}{R_1 R_2'}\right)\right] + \alpha_1 \qquad (6)$$

where $R_1 R_2' = R_1\sqrt{a_1'/a_2'}$ is the apparent ratio at the low power factor and $b_1' = b_2'$ as before.

From this we may derive the practical formula

$$\alpha_2 = \frac{3438}{\tan\theta}\left(1 - \frac{R_2}{R_1 R_2'}\right) + \alpha_1\ \text{(minutes)} \qquad (7)$$

Advantages of the Two-Stage Transformer

In conclusion it may be well to point out some additional advantages of the two-stage transformer.

From an engineering standpoint it is possible greatly to reduce the amount of copper and iron required to give results which are at least as good or better than now attained in the highest grade transformers produced. It is not necessary to have an accurate knowledge of the magnetic properties of the iron used. With reasonable amounts of materials used the inaccuracy of metering due to the presence of current transformers can be reduced to a negligible quantity. This is in contrast to the average simple current transformer whose accuracy under service conditions often leaves much to be desired. Even with a given secondary burden it cannot be compensated for all loads and power factors, as the curves clearly show.

The results of a questionnaire sent out recently to the large electric power companies by the Meter Committee of the National Electric Light Association[3] showed that, "The installation of separate current transformers was reported in practically all cases for watt-hour meters, while indicating instruments and other devices, including relays, are combined on the same transformer." The use of one two-stage transformer would give as good or better metering accuracy, and would save the cost of the extra transformer and the space occupied by it.

Current transformers of very large range, beyond the maker's facilities for precision testing, can be made with the assurance that by having approximately the correct number of turns in primary and principal secondary and the exact ratio of turns in primary and auxiliary secondary the ratio will be accurately correct and the phase angle negligible.

Transformers of ordinary construction of small number of secondary turns cannot be brought to exact ratio because it is not feasible to drop a fraction of a turn. This difficulty is absent in the two-stage transformer.

Since watt-hour meters operated from two-stage transformers do not need to be adjusted specially to offset transformer ratio and phase-angle errors, the work of testing such meters will be simplified and the cost of testing reduced.

An important possible application of the two-stage transformer is in the measurement of the output of a-c. generators on acceptance tests. In the case of large machines it is customary to stipulate a large penalty for each per cent by which the efficiency falls below the contract figure, and conversely a large bonus for an efficiency superior to that specified. It is therefore highly desirable to use current transformers which have a constant ratio and do not require troublesome corrections for phase-angle errors. The auxiliary winding can be applied to indicating wattmeters as well as to watt-hour meters.

Particularly on high-voltage circuits where accurate metering is so desirable the simple current transformers of best design show very poor characteristics. This is due to the separation of primary and secondary windings necessitated by the insulation requirements. This is particularly true of the Nicholson air-insulated transformer and the bushing type having low ampere-turns and long mean path of flux in the iron. In these cases the two-stage transformer will make possible a step well in advance of present-day methods of metering high-voltage systems.

Appendix

In the following discussion the mathematical relations underlying the action of the two-stage current transformer are established, and a comparison is made with the corresponding relations for the simple current transformer. In this connection the authors wish to acknowledge valuable assistance rendered by Dr. F. B. Silsbee.

The following symbols will be used:

I_0, I_1 and I_4 = primary, main secondary, and auxiliary secondary currents respectively

3. Report of N. E. L. A. Meter Committee, June 1921, p. 9, 44th Convention.

$X_0, X_1 \ldots X_4$ reactances of the several coils as indicated by the subscript and on Fig. 1

Z_3 = impedance of main burden plus resistance of coils 1 and 3

Z_4 = impedance of auxiliary burden plus resistance of coil 4

X_{01}, X_{23}, etc. = mutual reactances between coils indicated by the subscripts

$N_0, N_1 \ldots N_4$ = number of turns in coils 0, 1 . . . 4

μ_1, μ_4 = permeability of iron in main and auxiliary cores respectively

a_1, a_4 = cross-section of iron in respective cores

l_1, l_4 = length of magnetic circuit in respective cores

ω = 2 π times frequency

j = $\sqrt{-1}$

D_1, D_4 = leakage factors (approx. equal to 1)

$\delta_{01}, \delta_{23}, \ldots$ etc. = leakage differences

c = $\dfrac{a_4 \mu_4 D_4 l_1}{a_1 \mu_1 D_1 l_4}$

z_3, z_4 = Z_3/X_1 and Z_4/X_1 respectively

$\eta_{34} \ldots$ etc. = $\delta_{34} \mu_4$ . . . .

ζ = Z_4/X_4

Throughout the development, the currents, impedances, and permeabilities will be regarded as plane vectors and the final ratio will be obtained as a complex number whose modulus is the true ratio and whose argument is the phase angle.

Applying Kirchoff's laws to the two secondary circuits shown in Fig. 1 we obtain

$$I_1 [Z_3 + j (X_1 + X_3)] + I_4 j X_{34} = - I_0 j (X_{01} + X_{23}) \qquad (8)$$

$$I_1 j X_{34} + I_4 (Z_4 + j X_4) = - I_0 j X_{24} \qquad (9)$$

Solving these two simultaneous equations gives

$$I_1 = - I_0 \frac{j (X_{01} + X_{23}) (Z_4 + j X_4) + X_{34} X_{24}}{(Z_4 + j X_4) [Z_3 + j (X_1 + X_3)] + X_{34}^2} \qquad (10)$$

$$I_4 = - I_0 \frac{j X_{24} [Z_3 + j (X_1 + X_3)] + X_{34} (X_{01} + X_{23})}{(Z_4 + j X_4) [Z_3 + j (X_1 + X_3)] + X_{34}^2} \qquad (11)$$

Now each of the reactances (X_{mn}) may be split up into a number of factors so that

$$\left.\begin{aligned}
X_1 &= \omega \frac{4\pi}{10} \frac{a_1}{l_1} \mu_1 N_1^2 D_1 \\
X_3 &= \omega \frac{4\pi}{10} \frac{a_4}{l_4} \mu_4 N_3^2 D_4 (1 - \delta_3) \\
X_4 &= \omega \frac{4\pi}{10} \frac{a_4}{l_4} \mu_4 N_4^2 D_4 \\
X_{01} &= \omega \frac{4\pi}{10} \frac{a_1}{l_1} \mu_1 N_0 N_1 D_1 (1 - \delta_{01}) \\
X_{23} &= \omega \frac{4\pi}{10} \frac{a_4}{l_4} \mu_4 N_2 N_3 D_4 (1 - \delta_{23}) \\
X_{24} &= \omega \frac{4\pi}{10} \frac{a_4}{l_4} \mu_4 N_2 N_4 D_4 (1 - \delta_{24}) \\
X_{34} &= \omega \frac{4\pi}{10} \frac{a_4}{l_4} \mu_4 N_3 N_4 D_4 (1 - \delta_{34})
\end{aligned}\right\} \qquad (12)$$

In these expressions the leakage factors D_1 and D_4 are those by which the inductances of coils 1 and 4 respectively differ from those computed from the well-known simple formula for uniformly and closely wound ring coils. In the case of the other reactances the corresponding differences are allowed for by introducing the quantities δ which are in practical cases small compared with 1.

If we now limit ourselves to the practical case where $N_3 = N_4$ and $N_0 = N_2$, and for abbreviation let

$$c = \frac{a_4 \mu_4 D_4 l_1}{a_1 \mu_1 D_1 l_4} \qquad (13)$$

and also let $\quad Z_3/X_1 = z_3, \quad Z_4/X_1 = z_4 \qquad (14)$

we get, on making the various substitutions, the two equations:

$$I_1 = - I_0 \times$$

$$\frac{\dfrac{N_2}{N_1} \left\{ 1 - \delta_{01} + \dfrac{N_3}{N_1} c (- \delta_{23} + \delta_{34} + \delta_{24} - \delta_{34} \delta_{24}) - j \left[z_4 \left(\dfrac{N_1^2}{N_3^2 c} + \dfrac{N_1}{N_3} \right) - z_4 \left(\dfrac{\delta_{01} N_1^2}{N_3^2 c} - \dfrac{\delta_{23} N_1}{N_3} \right) \right] \right\}}{1 - \dfrac{N_3^2}{N_1^2} c (- \delta_3 + 2 \delta_{34} - \delta_{34}^2) - j \left[z_3 + z_4 \left(1 - \delta_3 + \dfrac{N_1^2}{N_3^2 c} \right) \right]} \qquad (15)$$

and

$$I_4 = - I_0 \times$$

$$\frac{\dfrac{N_2}{N_1} \left[\dfrac{N_1 - N_3}{N_3} - \dfrac{N_1}{N_3} \delta_{24} + \delta_{01} + \delta_{34} + \dfrac{N_3}{N_1} c (- \delta_3 - \delta_{24} + \delta_{23} + \delta_{34} - \delta_{23} \delta_{24} + \delta_3 \delta_{24}) - j z_3 \dfrac{N_1}{N_3} (1 - \delta_{24}) \right]}{1 - \dfrac{N_3^2}{N_1^2} c (- \delta_3 + 2 \delta_{34} - \delta_{34}^2) - j [z_3 + z_4 (1 - \delta_3 + \dfrac{N_1^2}{N_3^2 c})]} \qquad (16)$$

While these separately are very complicated functions of the leakage factors and burdens it will be noted that the δ's and z's are in practise small compared to 1 and hence we may neglect the higher powers and products of these quantities entirely. If this is done the division of numerator by denominator may be carried out explicitly and we obtain

$$I_1 = -I_0 \frac{N_2}{N_1}\Big[1 - \delta_{01} + \frac{N_3}{N_1} c\,(-\delta_{23} + \delta_{34} + \delta_{21}) - \frac{N_3^2}{N_1^2} c\,(2\,\delta_{34} - \delta_3) + \ldots + j\left(z_3 + z_4 \frac{N_3 - N_1}{N_3} + \ldots\right)\Big] \tag{17}$$

$$I_4 = -I_0 \frac{N_2}{N_1}\Big\{ \frac{N_1 - N_3}{N_3} + \delta_{01} - \frac{N_1}{N_3}\delta_{24} + \delta_{34} + \frac{N_3}{N_1} c\,(\delta_{23} - \delta_{34} - \delta_{24}) + \frac{N_3^2}{N_1^2} c\,(2\,\delta_{34} - \delta_3) + \ldots - j\left[z_3 - z_4\left(1 + \frac{N_1^2}{N_3^2 c}\right)\right]\Big\} \tag{18}$$

It will be seen that most of the terms (e. g., δ_{01}) of (**18**) are equal in magnitude and opposite in sign to the corresponding terms in (**17**), which is of course the mathematical expression for the physical fact that I_4 has very nearly the correct value to compensate for the departure of I_1 from its ideal value of $-I_0\,N_2/N_1$.

If therefore we compute the effective ratio in the usual form we get, after a rearrangement of terms

$$\text{Ratio} = \frac{I_0}{I_1 + I_4} = -\frac{N_3}{N_2}\Big\{1 - \frac{N_3}{N_1}\delta_{34} + \delta_{24} + \ldots + j\left[z_4 \frac{(N_1 - N_3)\,N_1}{c\,N_3^2} + \ldots\right]\Big\} \tag{19}$$

The corresponding expression for a single-stage transformer of the usual type is

$$\text{Ratio} = \frac{I_0}{I_1} = -\frac{N_1}{N_0}\,[1 + \delta_{01} + \ldots - j\,(z_3 + \ldots)] \tag{20}$$

A comparison of equations (**19**) and (**20**) shows at once the advantages of two-stage transformation. If N_1 is made equal to N_3 then the ratio in (**19**) becomes independent of the secondary burdens, and if in addition $\delta_{34} = \delta_{24}$ (*i. e.* if coils 3 and 2 have equal mutual inductances on coil 4) then the ratio becomes constant and equal to N_3/N_2.

To see in more detail the effect of various conditions on the operation of the apparatus we may make some further algebraic transformations and must introduce some physical assumptions. It is evident from (**20**) that if δ_{01} and z_3 were constants, ordinary current transformers would have a constant ratio and phase angle at any given frequency and burden. Consequently the entire variation of transformer ratio with current and the main part of its variation with frequency and burden are due to the fact that the permeability is not constant and the core loss does not vary in proportion to the square of the flux density. In the group of equations (**12**) no explicit mention was made of core loss but this may readily be taken care of by considering μ to be a complex quantity having a real component proportional to that component of the induced voltage in quadrature with the magnetizing current and an imaginary component proportional to the core-loss component of the induced voltage. The leakage differences δ are roughly a measure of the ratio of the air leakage flux peculiar to one coil to the total flux which is mainly in the iron. Consequently these quantities, roughly at least, will be inversely proportional to the permeability of the iron. Also the quantities z_3 and z_4 involving, as they do, X_1 or X_4 in the denominator will be inversely proportional to μ. We may therefore at least approximately set

$$\left.\begin{aligned} \delta_{34} &= \eta_{34}/\mu_4 \\ \delta_{24} &= \eta_{24}/\mu_4 \\ z_3 &= \zeta_3/\mu_4 \\ \frac{N_1^2\,z_4}{N_3^2\,c} &= \frac{\zeta_4}{\mu_4}, \quad \text{or} \quad \zeta_4 = \frac{Z_4}{X_4}\,\mu_4 \end{aligned}\right\} \tag{21}$$

Inserting these relations in (**13**) and (**14**) gives Ratio (two-stage) =

$$-\frac{N_3}{N_2}\left[1 + \left(\eta_{24} - \frac{N_3}{N_1}\,\eta_{34} + j\,\zeta_4\,\frac{N_1 - N_3}{N_1}\right)\frac{1}{\mu_4}\right] \tag{22}$$

and

$$\text{Ratio (single-stage)} = -\frac{N_1}{N_0}\,[1 + (\eta_{01} - j\,\zeta_3)\frac{1}{\mu_1}\,] \tag{23}$$

The equations cannot be profitably pushed farther than this unless the permeability can be expressed as a definite function of the flux density. It may be noted, however, that the flux density at which a core works is proportional to the net induced voltage per turn and varies inversely as the frequency. Consequently for high frequencies or small currents and burdens μ_1 will be small but fairly constant while with higher flux densities corresponding to lower frequency or larger current and burden μ will be larger but will vary more rapidly with current. Since the auxiliary core has to circulate only the very small auxiliary current through the very moderate auxiliary burden, the flux density in it is low and μ_4 in equation (**22**) is fairly constant, though small. In the single-stage transformer, however, the flux must be sufficient to circulate the entire secondary current and μ_1 in equation (**23**) will vary rather rapidly with current.

The principal gain from two-stage transformation, however, is seen by the coefficient of $1/\mu_4$ in equation

(22), which involves only the *difference* of two nearly equal leakage factors instead of a single factor. Moreover, the main secondary burden does not enter at all into the first order terms in equation (22) for the two-stage transformer, and the auxiliary burden is multiplied by the factor

$$\frac{N_1 - N_3}{N_1}$$

which is always small and may be made zero if desired. To make $N_1 = N_3$ however in general will make I_4 larger than if N_1 is slightly less than N_3. The consequent increase in auxiliary flux density and in the variability of μ_4 and in second order terms may more than neutralize the improvement in the ζ_4 term.

Equation (22) shows very clearly the effect of external mutual inductance between the main and auxiliary secondary circuits, since such an effect is equivalent to increasing η_{34} and will directly destroy the balance between δ_{34} and δ_{24}. This effect is referred to at some length in the present paper.

On the whole it is seen that the errors of the single-stage transformer have been reduced to one order of magnitude smaller by the use of the two-stage transformation. This is confirmed by the experimental results which show that a transformer which operating single-stage has errors of several per cent will on two-stage operation show errors of only a tenth of this amount, or less.

THERMOELECTRIC VS. PHOTOELECTRIC REACTIONS IN MOLYBDENITE

Some substances, when exposed to light, decrease in electrical resistance. This is commonly called a "photopositive" reaction. About two years ago, it was observed in the Bureau of Standards that when certain samples of molydenite are connected with an electric battery and exposed to certain wave lengths of light (blue, green and yellow) the electrical resistance is higher than when the sample is kept in the dark. This is called a "photonegative" reaction.

At the time this phenomenon was observed, tests were made to determine whether the molybdenite generated an electric current when exposed to light, without an impressed potential, and it was found that, if there is such a generation of electric current (whether thermoelectric or what might be called a "spontaneous" current), it is too small to affect the above-mentioned photonegative reaction.

Recently, Mr. T. W. Case raised the question whether this photonegative reaction is caused by an electric current, saying he had found that molybdenite is light active, *i. e.*, generates an electric current without an impressed potential. His method of making the test was to explore the illuminated surface (which is sensitive in spots) with fine wire electrodes and a galvanometer or a photophone. Since the thermoelectric power of molybdenite is very high, the question arises whether by this method of making the test some of the action is thermoelectric.

In view of Mr. Case's query, the photonegative action in molybdenite was reinvestigated. It was found that a small electric current is generated, without any impressed potential, but it is too small to affect the photonegative reaction previously observed.

Concerning the generation of an electric current from light, it may be said that numerous samples of molybdenite were examined, which generated a small electric current without an impressed potential, when exposed to light.

The tests were made by connecting the molybdenite with a sensitive Thomson galvanometer and exposing different parts of the sample to an equal energy spectrum. It was found that, on exposure to radiation, a small electric current is developed which is a function of the wave length of the light stimulus and of the thickness of the sample.

The maximum effect is produced by wave lengths of 0.7 to 0.8μ, and no effect was produced by wave lengths greater than 1μ. The effect may be "photopositive" and "photonegative" depending upon the wave length of the radiation stimulus, just as observed when there is an impressed potential. It is, therefore an interesting question whether all photoelectrical reactions in solids are an amplification of the effects produced without an impressed e. m. f.

The generation of an electric current directly from exposure of a substance to light (*e. g.* cuprous oxide in copper formate; probably photochemical) is not an entirely new phenomenon. Whether molybdenite belongs to this class remains to be determined. For in spite of this apparent selectivity of the reaction to wave length of the light stimulus (which can be explained on the basis of the variation in spectral transmission) some of the effects produced by thermal conduction (heat applied directly by touching the molybdenite with a hot wire) make the phenomenon appear to be thermoelectric, resulting from inhomogeneity and perhaps impurities.

BOOKLET ON AUTOMOBILE HEADLIGHTING

Professor F. C. Caldwell of Ohio University has recently written an interesting and instructive booklet on the subject of Autobmobile Headlighting. This booklet contains an analysis of the problem of automobile headlighting, recommendations as to the amount of light required for satisfactory headlighting, a review of headlighting regulations now existing in Ohio and a number of other states, and much useful information on the subjects of headlights, headlight lamps, spotlights and lenses. The booklet was written primarily for those residing in Ohio, and, therefore, subject to the headlighting regulations of that state. Copies of this booklet can be obtained upon request, however, from the Engineering Experiment Station of Ohio State University, Columbus, Ohio.

Baltimore Oil Circuit Breaker Tests

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Review of the Subject.—*In view of the tremendous growth of electric power systems it has been realized for sometime by many of the larger operating companies that many of the old circuit breakers were not adequate for the increased duty. There seemed also to be considerable uncertainty as to the actual ratings of many of the more modern types. It was realized that this condition was largely due to the fact that the manufacturer was handicapped in making tests due to lack of power. These circumstances led the Consolidated Gas, Electric Light and Power Company of Baltimore and the Pennsylvania Water and Power Co. to make a series of oil switch tests on their interconnected 13,200-volt, 25-cycle power system, cooperating with the Westinghouse Electric and Manufacturing Company and the General Electric Company.*

The largest generating capacity used on these tests was 170,000 kw. Currents obtained vary from 750 to 23,700 ruptured r. m. s. arc amperes.

All of the tests were made by throwing three-phase metallic short circuits directly on the system which the breaker under test was called upon to clear immediately. Proper protection of the system was provided in case of failure of test breaker.

Three oscillographs were utilized to record the sequence of events. A total of about 200 short circuits was made directly on the Baltimore system without any breakdown whatever of the major equipment of the two operating companies, and in practically all cases without causing more than a momentary voltage disturbance to the system.

The results as described in the papers submitted by Messrs. Hilliard and MacNeill indicate that it is possible with proper design to build oil circuit breakers which can be relied upon to satisfactorily interrupt large currents on high-capacity systems many times in succession without damage to the breakers, without oil throw, and without change of oil or adjustments.

CONTENTS

THE tremendous growth of electric power systems with corresponding increase in size and number of generators, feeders, transformers and other station apparatus, has thrown an ever increasing duty on the switching equipment. Likewise, the modern tendency to secure higher efficiency, economy and flexibility by interconnection of older systems and running all the generating stations in parallel, has still further augmented the burden of oil circuit breakers. The high degree of reliability and continuity of service generally expected, also necessitates high standards of oil circuit breaker performance. That not all of the oil breakers at present in service were able to meet these new demands, has been realized for some time by many of the larger operating companies. Older breakers were proving themselves inadequate for heavy duty, while breakers of later design were not entirely satisfactory. Some breakers failed to clear short circuits, were badly injured or completely wrecked, throwing oil and parts around by explosive action, with consequent danger to other apparatus and station attendants. Occasionally even serious oil fires would result from the failure of a breaker forcing the operators to abandon the station for a time. Even when breakers cleared they were frequently damaged, requiring the breakers to be carefully gone over, repaired, and adjusted and refilled with oil, before being put back in service. That is, many breakers could not be relied upon to handle more than one heavy short circuit without repairs or adjustments of some kind, making them virtually "one short" breakers. This limitation of the number of times a breaker could satisfactorily open heavy currents was indeed a serious drawback.

There has also been considerable uncertainty as to the individual performance and rating of the various sizes and types of oil circuit breakers. This placed the selection of the proper type and size of breakers for new services, and design of new stations on a very uncertain basis, with little exact information upon which to base designs and selection of sizes. With the large investments involved, this lack of exact knowledge made a most undesirable condition.

That this situation has existed for some time has largely been due to the fact that the manufacturers were handicapped in making tests to obtain the desired information, by the lack of sufficient power which would approximate conditions on actual power systems. Tests have been made before, but these were generally few in number or involved relatively small capacity, as most operating companies were averse to risking their equipment in any extended set of tests. Still this was necessary as a very important consideration is that small generator capacity not only limits the short circuit currents to low values, but causes the voltage to fall off so rapidly that a breaker opens a very low voltage, thus destroying the value of tests made under these conditions.

These circumstances and conditions caused the Consolidated Gas Electric Light and Power Company of Baltimore and the Pennsylvania Water and Power Company to make an elaborate set of oil circuit

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breaker tests on their interconnected 13,200-volt, 25-cycle power system, in cooperation with the Westinghouse Electric and Manufacturing Company and the General Electric Company, which furnished the switches tested. Generator, transmission line and cable capacity were furnished equalling or even exceeding normal operating conditions. The fact is the currents obtained in the tests exceeded those usually met with in short circuits on this system. All the tests were made by throwing "dead" metallic short circuits on the entire connected system, which the breaker under test was called upon to open.

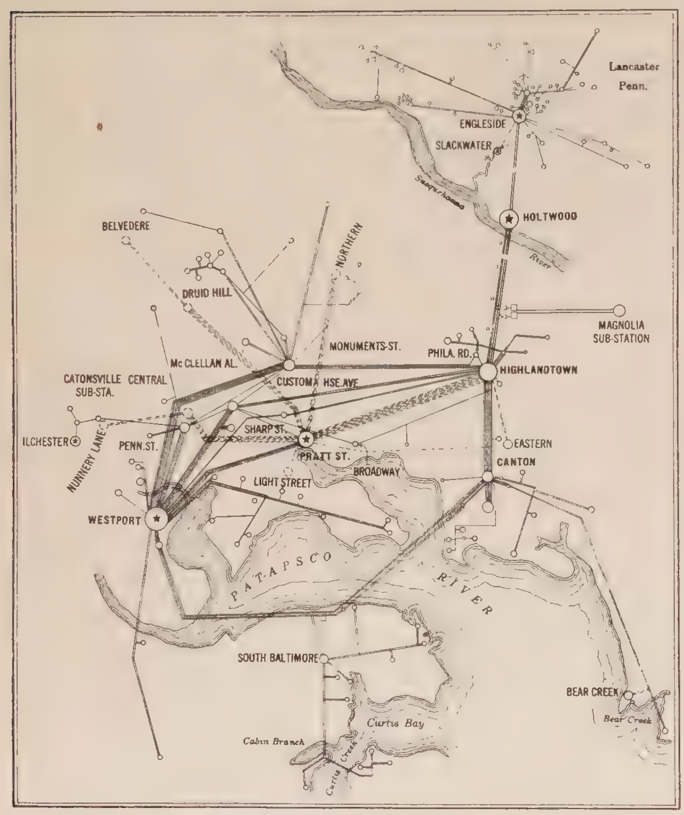

Fig. 1—System Diagram

Baltimore Gas, Electric Light and Power and Pennsylvania Water and Power Companies.

The Canton substation in Baltimore was selected as the best location for these tests for several reasons:

It is situated about seven miles from Westport, the main steam generating station of the Consolidated Company, and about forty-one miles from the hydraulic power plant at Holtwood of the Pennsylvania Water and Power Co. and current can thus readily be supplied from both of these generating stations over a large number of cables and transmission lines, as shown in Fig. 1. The current in this way becomes well distributed on the generators, transformers and feeders, without excessive overloading of any individual units.

Some other locations such as Westport might have given higher initial currents, but these would have caused the voltage to fall off more rapidly due to greater demagnetizing action, thereby making it questionable whether the breakers actually would be subjected to a more severe duty than at Canton. Actual test results showed the great effect of sustained voltage. The voltage at Canton, *i. e.*, the re-established voltage, appearing right after the short circuit was cleared was never less than 77 per cent normal voltage, even after the heaviest short circuits obtained, and on lighter short circuits was practically normal.

Furthermore available space at Canton permitted of convenient arrangement of sheds sheltering oil breakers under test outside of the station. These also could be located so as to be of little or no hazard to either the company's or other people's property in case of failure of the switch. It was, also possible for observers carefully to watch the tests at a safe distance with little danger to themselves.

Capacity of System

The main steam generating station of the Consolidated Gas Electric Light and Power Company, which is located at Westport, has a generating capacity of 127,500 kw. in steam driven turbo-generators, of which 87,500 kw. was usually available for tests. The generating station of the Pennsylvania Water and Power Co., at Holtwood, Pa., has a generating capacity of 83,500 kw. in water-driven units. There is also one 20,000-kw. steam-driven unit at the Pratt St. Station in Baltimore. These three generating stations are interconnected through a number of substations, giving the system a combined generating capacity of 231,000 kw. The maximum generating capacity used in these tests was 170,000 kw. Canton substation is directly connected with the Westport steam station by four 26,000-volt submarine cables, banks of transformers being provided at either end, and is also tied to the city network by eight 13,200-volt cables through the Pennsylvania Water and Power Co. Highlandtown substation.

As breakers of various rupturing capacities were tested, it was necessary to get various values of short-circuit current. Also, some tests were made by starting in at low values of current.

To obtain these short-circuit currents of different magnitudes the number of generating units was varied to some extent, but the main variation in current was obtained by changing the cable connection between the generating stations and the test bus at Canton substation so that even in the case of the minimum current used a very large capacity was behind the short circuit. From the constants of the system the short-circuit current of a large number of possible combinations of generators, transformers, and transmission arrangements were thus calculated and these figures used as guides for our set-ups in the tests. A typical arrangement used is shown on Fig. 2. It is perhaps remarkable to note that these calculations came within 5 to 15 per cent of the currents actually obtained in the tests at the time of rupture.

Currents Obtained

All the tests were made at 13,200 volts, 25 cycles. Short circuits ranging from 950 to 30,800 initial r. m. s. amperes and from 750 to 23,700 ruptured r. m. s. amperes were obtained. The water-power station being far removed from the test bus supplied about 30 per cent of the initial short-circuit current, 70 per cent being supplied either by Westport alone or by Westport and Pratt St. stations. The maximum

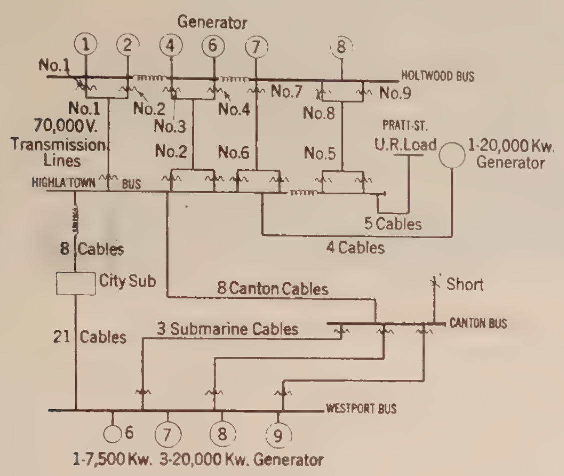

Fig. 2—Typical Test Arrangement of System

Calculated short-circuit current:
Initial = 29,400 r. m. s. amperes at 42.2 per cent power factor.
After 5 cycles = 24.850 amperes at 39.3 per cent power factor.

instantaneous loads on any of the generators did not exceed five times the normal load. Under the heavy short circuits, some cables (4 0) carried from 2000 to 2500 amperes.

Most of the short circuits were made across all three phases and ground. A few were across two phases and ground, and several on one phase and ground only. After finding that two-phase and single-phase short circuits produced severe vibration of turbo-generators, they were subsequently avoided. In this connection it should be pointed out that in the Baltimore system the neutral of all generators and transformers is "dead" grounded without any resistance, so that in each three-phase test it was necessary for each individual phase of the oil circuit breaker to clear its own part of the short circuit without any help from the other phases, as might have been the case in any ungrounded or partially grounded system.

Test Breaker Arrangement

The general method of testing was to throw a dead short circuit on the breaker under test, which was set to open instantaneously. Two other oil circuit breakers were in series with the test breaker serving as protective breakers in case of failure of the test breaker, being set for later opening. A separate switch was used to act as closing-in breaker exclusively. There were thus four breakers in all used in the test circuit, which was connected to the system set up to give the desired currents.

Fig. 3 shows the arrangement of the four breakers in detail. The breaker under test was next to the short-circuit connection, which provided a metallic short circuit between all three phases and ground. It was arranged to trip automatically by means of a plunger type relay with "instantaneous" time setting, the only delay being that due to the inherent characteristics of the mechanism and relay. This varied from three to nine cycles (0.12-0.36 sec.) The closing in breaker was non-automatic and was closed by means of a switch under the control of the oscillograph operator. The protective breakers were operated by Westinghouse type CO time element relays. In the earlier tests both of these breakers were operated by the same relays so that they would open simultaneously. In the later tests one of them located in the test shed, was set to open in about 10 cycles (0.4 sec.) after closing of the short circuit, so as to be the first to operate in case of failure of the test switch or other damage. The other protective breaker was in the bus structure of the station itself, being part of the station equipment, thus acting as the connecting link between the test circuit and station bus. It was set so as to open in about twelve cycles (0.48 sec.), or a few cycles later than the other protective breakers. This combination afforded protection not only against failure of test breaker, but against failure of closing-in breaker, or one protective breaker, also breakdown or short circuit of leads. Some of these different troubles were experienced during the tests. Both of these schemes of protection proved to be absolutely adequate throughout the many tests, as in no case did the protective breakers fail to clear the test equipment from the bus in the station.

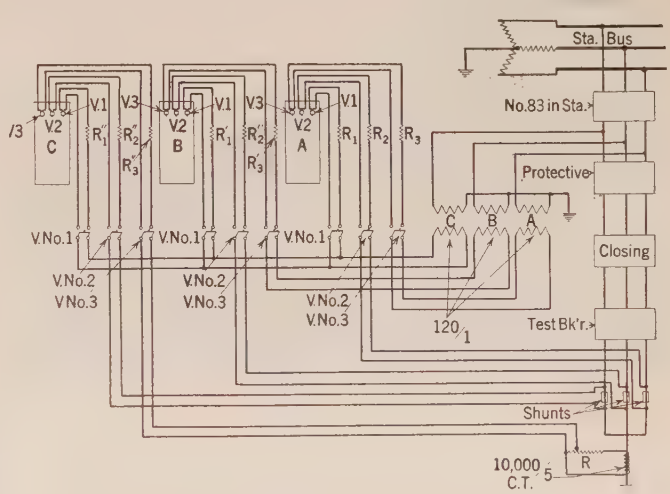

Fig. 3—Diagram of Test Breaker Arrangement and Connection of Oscillograph Elements

Test Sheds

The test breakers were placed in temporary sheds about ten feet from the station. Three breakers were originally placed in one shed, but as injury to the test breaker in early tests was communicated to the others

a second shed was built and the test breaker placed in it. The general arrangement is shown in Fig. 4. Doors were put in the ends of each shack, providing accessibility and ease of observation.

Sheds were built of wooden framework, covered on the inside with galvanized corrugated iron as a protection against the weather and fires. The floor of the first shed was dirt at first, but this was replaced later by a wooden floor to which the switches could be bolted to keep them from rocking. The floor of the second shed only was made of concrete.

Leads

Leads to sheds from the station consisted of lead-covered varnished cambric single-conductor cables, size 4/0. These were brought to the sheds in tile ducts. Leads in the sheds to switches were flameproof varnished-cambric, rubber-insulated wire.

It was learned by experience that the leads had to be carefully and securely braced. Magnetic stresses produced by heavy short-circuit currents caused a great tendency of leads to shift and whip, sometimes resulting in breakdowns. It was also found that very careful attention had to be given to soldered joints and connections, as repeated heavy currents by heating and pulling action caused defective joints to open up with consequent arcs, which sometimes spoiled the tests and often damaged other parts. Not only did this pertain to the connections in the test sheds but it was also of special importance in the leads in the station connected with the test, in order to prevent trouble being communicated to the rest of the station, as occurred in one case with considerable damage. Therefore, in the station proper, all buses were carefully gone over and specially braced. Disconnects were also given special attention, in fact, some of these were eliminated in any cables which carried excessive currents.

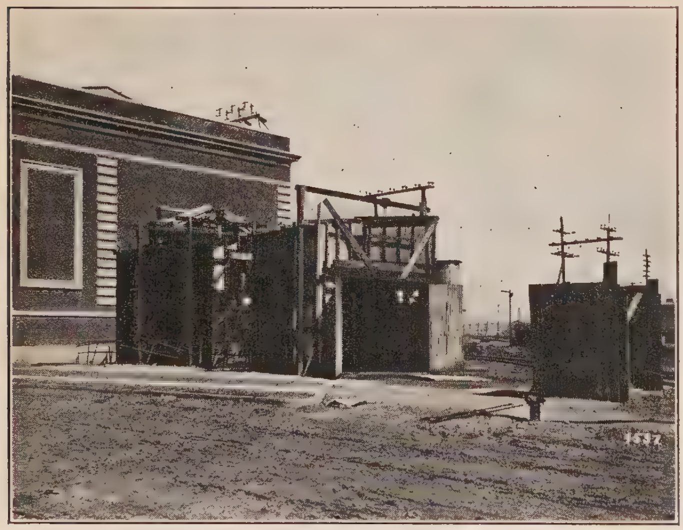

Fig. 4—Test Sheds

Fig. 5—Oscillographs and Control Apparatus for Tests

Measurement of Time, Currents and Voltage

Three oscillographs containing three elements each were used, thus making a total of nine elements, and three films. Each of these generally recorded the current in one phase and corresponding voltage to ground. In order to provide a common timing curve two of the films in addition to their own voltage (to ground) also recorded the voltage corresponding to the third phase. The third film in addition to its phase current and voltage also recorded the ground current.

Potential transformers were connected from each phase to ground at a point between the two protective breakers, thus providing a measure of voltage across each phase of the test breaker, showing in succession

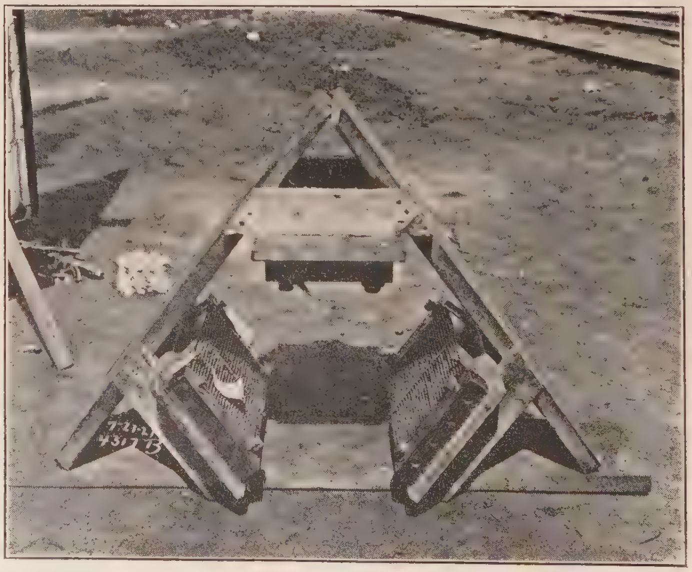

Fig. 6—Laminated Shunts, 10,000-Ampere, Placed in a Triangular Frame

full voltage before the short circuit, zero voltage and arcing voltage during the short circuit, and the re-established voltage after the short circuit was cleared, thus indicating the action of the various breakers. Fig. 5 shows a typical arrangement of these oscillographs.

In some cases it was desired to accentuate the scale of the arcing voltage, in which case one potential transformer was connected directly across one phase of the switch, and oscillograph resistances adjusted to give heavy deflection even at low voltage. This put excessive currents in the vibrator circuits, so a gold-leaf fuse was inserted in this circuit, which blew at high voltage which occurred due to complete restoration of voltage across breaker contacts on opening up. This scheme could not well have been used on all phases as it cut out other useful and necessary information obtained with the regular connection. A study of the voltage at the arc was also obtained by making photographic enlargements of parts of the oscillograms of voltage waves taken in the regular way.

For current measurements, slip-over type current transformers were used by one manufacturer. These were put on the line between the two protective breakers. The other company used shunts to measure current. As the use of these brought the oscillograph elements to the same potential as the shunts, these shunts were put in the leads at the short-circuited and grounded end of the test breaker. To further insure keeping this grounded end at ground potential and prevent the burning open of this ground, the size of this ground wire was doubled, two 4/0 wires being used. The scheme worked out generally satisfactorily, as no markedly bad effects were experienced, although shunt leads were charred in the conduit several times.

In the first tests the shunts were located in the same plane. In later tests they were located in the corners of a triangular wooden frame with axes parallel to incoming current leads, see Fig. 6. Care was taken to bring the instrument leads out from the center line of the shunts. These instrument leads consisted of twisted pairs; an important consideration, as failure to twist these leads in early tests had caused errors due to inductance effects. The latest arrangements of leads and shunts were made so as to reduce the effects of inductance to a minimum; in fact results indicated these to be practically negligible.

Current transformers and shunts each have their particular advantages as well as faults. There is some question as to how accurately current transformers record transient phenomena. Furthermore the partial saturation of the iron produced by heavy overloads during short circuit introduces other errors. However, current transformers can carry surprisingly heavy overloads with a fair degree of accuracy. It should be remembered that the oscillograph itself has but limited accuracy. On the other hand shunts record accurately transient phenomena. They are, however, subject to inductive effects, which can introduce considerable error. The uneven distribution of current in these may also introduce other, though probably slight errors. The ever present danger of putting line voltage on the oscillograph is of course a serious objection.

Oscillograph Layout

In the Westinghouse tests three oscillographs as developed by J. W. Legg were used. The special features of these oscillographs are described in detail in the July, 1920, Journal of the A. I. E. E. and will not be dwelt on here, except to point out such outstanding features as the use of incandescent lamps instead of arc lamps as a source of light, and the automatic arrangements which make it possible to secure the start of the short circuit at the beginning of the film, thereby making it possible to use satisfactorily short films only 12 in. long. In the G. E. tests, three standard G. E. oscillographs were used, all driven from the same jack shaft. 24-in. films were used, and the general method adopted was to start the oscillograph a moment before the short circuit was applied, and then close in the oil switch which applied the short circuit to the system independent of the oscillograph, both the switches controlling the oscillograph and the closing-in breaker, however, being under the immediate control of the oscillograph operator.

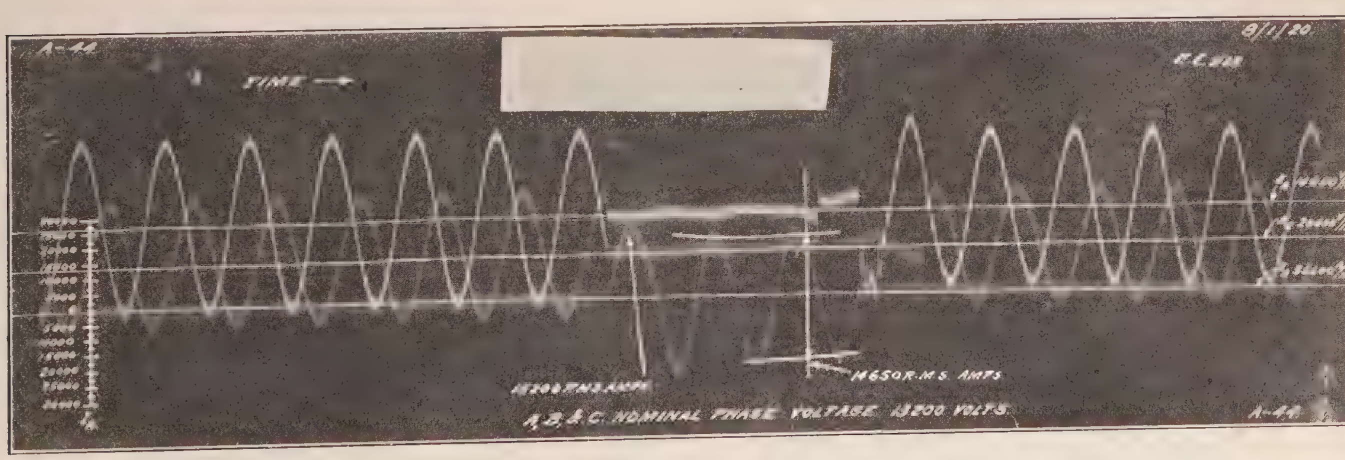

Fig. 7—Typical Oscillogram

Analysis of Oscillograms

Fig. 7 shows a typical oscillogram. The bottom curve represents the current in A phase and the top curve the corresponding voltage measured to ground. The middle curve represents the above mentioned reference voltage (C phase). It will be noticed that A-phase voltage becomes zero the moment the short circuit current appears, but later on reappears as a typical "arcing voltage", with the well known flat arc characteristic, corresponding to the instant the arcing contacts separate. After a little over one-half cycle of arcing the current in this case is ruptured and practically normal phase voltage reappears. By far the larger percentage of short circuits seem to break the arc at the zero point of the current wave corresponding to the time at which the magnetically stored energy of the system is a minimum. Occasionally exceptions are found to this rule. Oscillogram Fig. 8 shows such a case where the arc broke about 1/10 cycle after passing through its zero point. The method adopted in determining the r. m. s. current value from the oscillograms was the one described in the A. I. E. E. paper of February 19, 1918, by Messrs. Hewlett, Mahoney and Burnham on the rating and selection of oil circuit breakers. Illustration Fig. 9 shows the application of this method in detail in one particular case. As indicated, the current is divided into an a-c. and a d-c. component whenever unsymmetrical and the true r. m. s. value of current at any moment is obtained by combining the effective a-c. component ($I_{a \cdot c \cdot}$) and the d-c. component ($I_{d \cdot c \cdot}$) in the usual way, *i. e.*,

$$I_{r \cdot m \cdot s \cdot} = \sqrt{I^2_{a \cdot c \cdot} + I^2_{d \cdot c \cdot}}$$

To determine the true r. m. s. value which the breaker interrupted, the component parts are taken from the films at the moment the arc voltage first appeared, *i. e.*, at the instant the arcing tips parted. At this time in most cases, however, the d-c. component of the current wave was usually negligible. To determine the maximum r. m. s. obtained on the short circuit, the components parts were taken at the peak of either of the first two half waves, depending on which was the largest. Unless specifically stated otherwise, all the current values quoted in this and subsequent papers refer however to the actually ruptured arc amperes and not to the initial amperes.

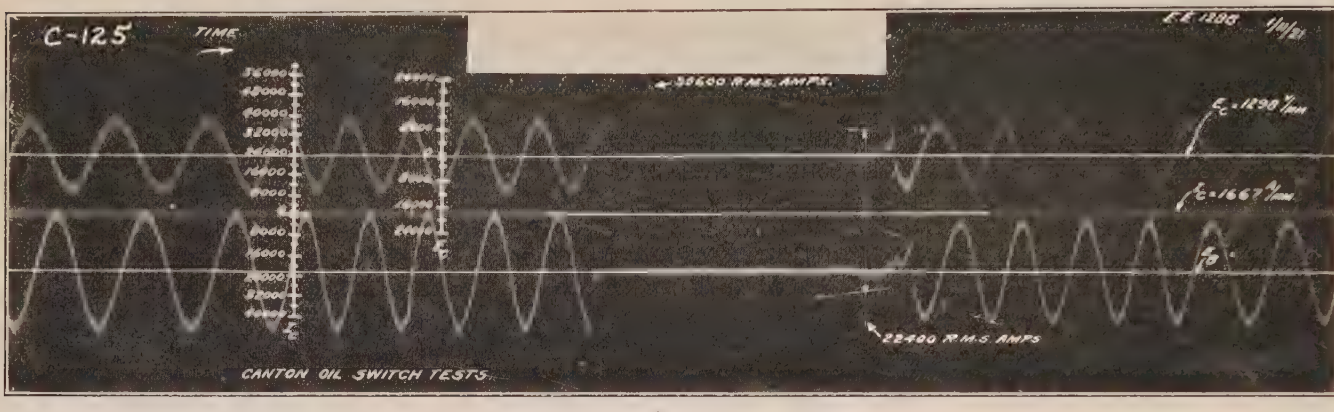

Fig. 8—Oscillogram showing Current Ruptured Past the Zero Point

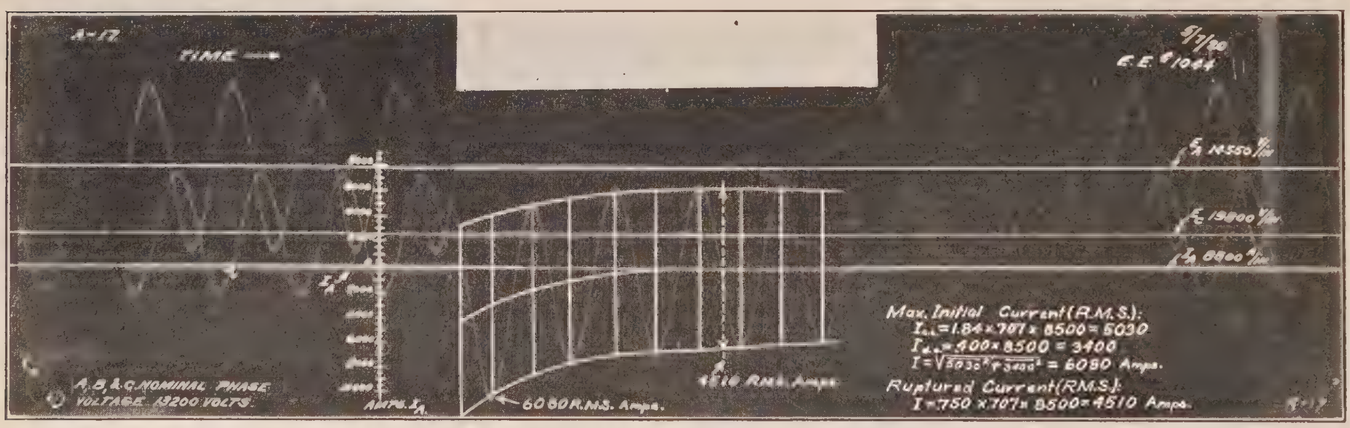

Fig. 9—Oscillogram showing Method Used in Calculating the R. M. S. Values

Effect on the System

It may be interesting to note that it has been possible to make a total of about 200 short circuits directly on the Baltimore system at Canton, many of which

involve the largest short circuit obtainable at this place without any breakdown whatever of the major equipment of the two operating companies, and with no more than two serious disturbances resulting to the system, one being due to the opening of a disconnector in the station, and the other being caused by the burning open of one of the leads in the station at its terminal. All of the tests naturally meant momentary voltage disturbances to the system, and for this reason most of the tests were made after midnight or on Sunday morning when such momentary disturbances could best be tolerated. In some of the later tests the load of a number of the more important customers was also carried on separate generators apart from the tests. In no case did the two power companies generators fall out of step, and in only a few cases was any of the customers' synchronous load lost momentarily. The most sensitive equipment on the system seemed to be the rectifiers used for street lighting which frequently would drop out, but as these could always be re-started immediately, this was not considered of serious consequence. The chief reason for the fact that it was possible to make so many short circuits with so little serious interference with the system lies undoubtedly in the short duration the short circuit was permitted to hang on to the system, usually not more than ¼ second and never more than ½ second. Additional reasons may be the fact that short circuits were not made directly at the generating stations so that there would always be some voltage left on the generators to maintain synchronism, and the fact that the system in question is equipped with a carefully designed and adjusted selective relay system.

Conclusions

In the papers presented by Messrs. Hilliard and MacNeill the individual performance of a number of breakers are described in detail and will therefore not be dwelt on here. A study of these papers will show that the tests have resulted in marked improvements in the design and performance of oil circuit breakers for moderate voltage and high interrupting capacity. The results unquestionably indicate that it is possible, with proper design, to build oil circuit breakers which can be relied upon to satisfactorily interrupt large currents on high-capacity systems many times in succession without damage to the breaker, without any oil throw and without change of oil or adjustments.

The tests have also proved that it is possible to conduct a series of tests directly on a modern system without damage to equipment and without serious interference to its normal operation. It is hoped that this fact will encourage other operating companies to cooperate with the manufacturers in further improvements of oil switches of other designs and ratings to the benefit of the whole industry.

INSTALLING INCANDESCENT LAMPS PROPERLY

From time to time incandescent companies receive complaints of lamps becoming inoperative by the loosing of the brass shell, commonly called the base, from the glass bulb. Inasmuch as the operation whereby the base is affixed to the bulb receives in the selection, formulating and processing of materials the same careful attention and scientific treatment that is accorded other operations in the art of lamp making, it was thought that the cause of many basing failures might be the imposing of unwarranted stresses when installing the lamp. A test was therefore made by one lamp manufacturer to determine the stresses actually imposed by different persons when installing lamps in sockets.

These tests, in which were employed seventy-seven persons of a great number of vocations and of different physical strengths, showed that the torque imposed by different individuals varied widely indeed. Taking the average of the torque values registered for 154 trial installations as a comparison figure, the torque values for the individual cases where this average was exceeded are expressed in terms of this average value:

No. of Cases	Per Cent
seven	115
four	154
eight	193
one	270
four	385
one	462
two	500
one	538
two	577
two	654
one	770
two	846
one	962

These results show that in a large percentage of commercial installations unwarranted stresses may be commonly imposed on lamp sockets. The higher torque values were registered by those individuals who, after rotating the lamp into the socket until the spring clip on the top contact was depressed, then seized the lamp in a full hand grip and gave it a quick final turn. It was noted during the tests, however, that in practically every case where low torque values were recorded, the subject held the lamp lightly, with only the tips of the fingers in contact with the bulb. The conclusion was reached, therefore, that this latter method was the most satisfactory method of installing incandescent lamps.

Electric lighting companies in England are making substantial rate reductions. In some instances the new schedules appear to have been developed so as to make possible a much broader use of electrical equipment for domestic purposes, indicating a tendency toward the wider use of household labor-saving devices.

Some Suggestions for Possible Improvements in Methods of Engineering Education

BY B. G. LAMME
Member, A. I. E. E.
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Attention is called to the fact that very few of those who take engineering courses in the colleges are fitted by previous mathematical training to take up the work properly. Suggestion, therefore, is made that all engineering courses drop back into the more elementary mathematics during the first year, in order to give a thorough drilling in the practical use of such mathematics, with a view better to fitting the students for more advanced work. It is believed that with this elementary training the students can make much more rapid progress in their advanced work, not only in engineering work, but in physics, mechanics and various other related lines.

Moreover such a course would assist the schools in eliminating those who are totally unfit for engineering work, and thus overcome one of the most serious defects of the present technical courses. The application of mathematics to practical work should be taught much more thoroughly than at present, but that appears to be impossible under the present circumstances where the students have a very incomplete elementary training.

IT may be that all real engineers are born engineers, or, on the other hand, it may be that the necessary fundamental traits are acquired *in very early childhood.* The personal experience of the writer, based upon intimate knowledge of hundreds of variously trained engineers, indicates that the real engineering traits are not acquired, to any great extent, in later childhood. But it is possible, in some few instances, that the necessary traits are present in early childhood but do not come to the front until later. However, in practically all cases of successful engineers, within the writer's experience, these traits were easily recognizable in the very early years. In fact, of the majority of the cases it might be said that the successful ones were about as good engineers at six years of age as at twenty-six, taking into account their relative knowledge and training at those respective ages. As to these traits being acquired in very early childhood, a leading engineer and educator once remarked—"The child may get some kind of a fatal twist or kink which starts him in a certain direction, and he keeps on growing that way." This is not at all unreasonable. The small boy who can "do" things or can "fix" things, naturally is called upon by his associates to do much of the fixing and mending that is required for their playthings, etc. In consequence, he gets all of the practise and becomes relatively more experienced than his playmates. The same thing may be said of mathematics. The small boy who becomes "handy at figures" is very often called upon for assistance by his schoolmates and playmates, and, in consequence, he does the helping while the others are helped and he thus gets ahead of them. Once in the lead he finds such things are easier for him and he more or less follows the path of least resistance. Thus whether the necessary traits were born in him, or are acquired in very early childhood, the natural tendency is toward cultivation, or exaggeration, of these traits through the normal activities of the child.

A symposium to be presented at the Annual Convention of the A. I. E. E., Niagara Falls, Ontario, June 26-30, 1922.

Two of the most valuable traits that a small child can have is the ability (1) to use his head, and (2) to use it in a more or less quantitative way. By the latter is meant that a child with a quantitative sense has a great advantage over others. Apparently this sense can be cultivated and quite highly developed in early childhood by proper direction, and here is probably where the real training of the engineer should begin. From the writer's own observations, and from discussion of the subject with many others, he is firmly convinced that one of the best trainings that the child could have is the old-fashioned kind of "mental arithmetic." This seems to have been largely abandoned in recent years, due doubtless to the inability of the teachers to handle it properly. Mental arithmetic, if properly taught, develops quickness in thinking, and also a quantitative or numerical sense which is of utmost value in later years. In fact, a numerical, or dimensional, or quantitative sense, whatever you want to call it, if highly developed, is one of the greatest assets that an engineer can have, and it is doubtful whether this sense can be acquired properly except in comparatively early years. The man with a quantitative or numerical sense can see relationships and can reason from cause to effect to a degree, in some cases, which seems uncanny to one not possessing this trait.

Obviously, therefore, one of the first great errors in our engineering education is the improper or insufficient training in the earlier years, and it is impossible to estimate what an enormous handicap this puts upon the colleges. The earlier training too often tends to suppress imagination and independent methods of thinking. The child is taught to do things by rule, and if he happens to develop, through his own originality, a new method of solving a problem, for instance, in his school work, far too often he is criticised instead of being commended. The arbitrary methods of teaching by fixed rules, by some incapables in our public schools, is one of the curses of the country. The old-fashioned country schools with a single teacher who handled the entire work, quite often developed

stronger mentalities than the modern supposedly much higher class schools.

It must be, and probably is, well recognized that the colleges can only cultivate existing traits, but cannot create new ones. As a prominent educator once said, "You can hatch only a gosling from a goose egg." The colleges, therefore, are handicapped in attempting to create traits and characteristics, in many cases, where such do not already exist. They are asked to build engineers out of non-engineering material,—an impossible task. Even with the modern supposed improvements in the public schools and high schools, the requirements of good engineering material, as far as the colleges are concerned are worse than they were some years ago, simply because of the enormous growth of the college population within the past few years has brought in many men of less suitable characteristics and traits than in former years. It has seemed to the writer that, many years ago when engineering education was less popular than at present, a fairly large percentage of those who sought an engineering education were men who had the "urge" or "call" for such work. Very often these were men who recognized that engineering was their life work, and who realized quite fully that an engineering training would be of great assistance to them. Such men very often were the outstanding younger men of their generation. Such men are also to be found at present, but it is questionable whether they have grown in numbers proportionally any faster than the total population of the country, whereas the technical school population has grown probably ten times as fast. If such assumption is reasonably correct, then the technical schools are being very greatly diluted, or adulterated, by those who may be classed as the unfit, in the true engineering sense. If such is the case, engineering education is bound to be on the down-grade sooner or later, unless steps are taken to correct the evil. The insolubles, so to speak, must be precipitated. Here is a truly big problem. The unfit in engineering may be the fit in something else and naturally we do not wish to prevent any one from getting a college education when he really desires it. At the same time those who "belong" in a given technical course should not be handicapped by those who do not belong. Otherwise, as the writer has stated repeatedly in the past, the training tends naturally toward mediocrity, for the poorer men are a drag upon the better ones. In fact, if the course is laid out for the average man, the less able students will have to work much harder than the better ones, whereas the more capable students, or those of stronger mentalities, should be the ones who receive the most drastic training, for our future engineering development depends very largely upon them. These should be trained to the utmost, and this is not possible, with many of the technical courses, as now constituted. This condition is well recognized in many of the schools and various attempts are being made to rectify it. As one prominent professor stated recently,—he has arranged his courses in two sections, one of which embodies the "slow freights" and the other the "fast expresses." In the former are included those with insufficient ground-work, or who are not capable of keeping up with the latter division. If any student in the "slow freights" is able to speed up sufficiently to keep pace with the "fast expresses" he can be transferred. This arrangement is an incentive to the better class of men, and, to a certain extent, removes the handicap previously described. Other schools have proposed so called "professional" and "non-professional" courses. The professional courses would take in those who have real aptitudes for engineering, while the other would include young men who desire a technical education for general purposes, but who have no strong call for true engineering.

As stated at the beginning of this article, the necessary traits of the real engineer are usually to be noted in early childhood. This should really form one of the deciding points in selecting those who should take the better engineering training, or who should be given the preference in such work. Such traits, along with a certain amount of mathematical skill and ability are necessary in real engineering, and, therefore, these should be given preference in the decision as to whether the young man is to take up an engineering course or not. This brings up the subject of mathematics, upon which something pertinent can always be said.

As has often been said in the past, one of the principal weaknesses of the engineering students lies in their inability to *use* ordinary every-day mathematics. Here and there one or two can really use their mathematics in a common sense way, but such cases are quite rare, based upon personal experience with large numbers of especially selected college men. Such criticism has often been made, but, in itself, does not help materially except to call further attention to what is already fairly well known. The writer is now going to suggest a partial remedy, which many educators may consider as unduly radical and a big step backwards, but which, in the end, should mean greater progress in the right direction. A step backward is all right at times, especially in those cases where one is going in the wrong direction; and, apparently, at present, many of the college courses are going in the wrong direction in their mathematical training.

The suggestion is embodied in the following: A great majority of the college men, in the technical courses, have had their preliminary training in algebra, geometry and trigonometry in the high schools, and such training as experience shows, is totally inadequate as a basis for the future work of the engineer. It is inadequate largely from the fact that only one student in possibly twenty-five ever sees or is shown

any real use for algebra and trigonometry. It is a study with him purely, and real practise does not enter. This condition is more or less inherent in the high school training, and such training, therefore, should not be accepted as a basis or foundation for future solid technical training. The suggestion is this,—that the engineering courses in college, especially the mechanical and electrical engineering courses, *should drop back one year in their mathematics.* This suggestion may raise a cry of protest, but nevertheless, it will appear that in the long run this dropping back is more imaginary than real. What is meant is that the first year in college should take up again the purely elementary algebra and trigonometry, as now covered by the high schools, but with the difference that this first year's work should largely consist in *the application to practical problems.* If the student cannot learn to *use* algebra and trigonometry practically and skillfully, in their elementary forms, he cannot expect to use them intelligently in their more advanced forms, such as in the calculus and other work. Therefore, as said before, this first year in mathematics should be expended largely in purely elementary algebra and algebraical trigonometry, involving the necessary small amount of theory and a great deal of practise in the form of various problems. These problems should be of such a nature, in many cases, that the elementary algebraical and trigonometrical expressions are not already formulated, but the problem should be of a descriptive nature, requiring the student to develop or formulate his own equations. Herein lies a great weakness of the students. Many of them can handle equations already set down for them, by following certain fixed rules which they have learned, (this is the mechanical part of mathematics) but many of these same men cannot possibly formulate the problem in the first place.

The result of this teaching would be far reaching. In the latter half of the freshman year, for instance, the class could be led gradually into more difficult problems, involving more advanced algebra and trigonometry of a practical nature, and by trigonometry is meant analytical or algebraical rather than simple plane trigonometry. In this way the student can gradually be led into the more difficult work by easy stages and he will acquire, if he is at all capable of it, a broader understanding of the general principles of elementary mathematics. He will build up a foundation for his future mathematics especially from the practical standpoint,—and engineering primarily is built upon practical mathematics.

In the teaching of practical mathematics, however, a distinction should be made between what one of the writer's old-time professors used to designate as "mathematical gymnastics" and "horse sense mathematics." By the former he meant the kind of mathematics where everything was carried into mathematical formulas, ofttimes of more or less complex nature, when the use of a little "horse sense" would have allowed the result to be obtained directly with no equations whatever. Such spectacular exhibitions of mathematical symbols are too often considered as the primary object in view. Too often also, the actual result which is striven for, is entirely hidden by the mathematical machinery used in producing the result. The students should become imbued with the fact that their mathematics are simply attacking tools or weapons and that an exhibition of the tools themselves is not of first importance. They should also be taught to understand that really good mathematicians very often can, and do, reach the desired results with but little or no evidence of the merely mechanical part of their work, and that mathematics really must be considered, in general, as simply a very effective mechanical aid to our methods of reasoning. For instance, one can take a physical fact and express it in mathematical symbols and then by rigid mathematical operations may transform the formula into some different one which expresses another physical fact. The mathematics here represent simply accurate or rigid methods of reasoning from one fact to another related one.

Returning to the subject, an important result of this first year's training would be that it would assist the teachers to separate the capable from the incapable, in the engineering sense. Those who prove totally unable to grasp the practical application in the early and easy stages of the work could then be weeded out, so to speak,—that is, they could be transferred to other courses where practical mathematics are less needed. Those who are mentally capable in practical mathematics but who have had a very poor foundation in their previous training, would have an opportunity to catch up and thus would suffer no handicap in their later work. This would be a great step in the right direction, and one of the great advantages which would accrue from such training would lie in the weeding out of the unfit from the engineering courses proper, as stated before. This would be a very great step in advance, as it would remove the present great handicap which the lagging classmen impose on their more advanced fellows.

It was suggested, as a first step, that the engineering schools drop back a year in mathematics. However, upon reaching the second year in the engineering classes, it is the writer's opinion that the survivors of the above first year of training could handle their mathematical subjects, as well as physics and other subjects, in so much better manner that, by the end of the second year they would actually be farther along mathematically than with the present course of training, due to the fact that the fundamental training is so much better. Unquestionably with a training of this sort, those who take up studies requiring analytical work of a mathematical nature, for instance, would obtain a far better grasp of the subject, and in many other engineering subjects they would tend to get

at the fundamentals far better than is possible under the present training. With such a course of training, the average engineering student, by the end of his senior year, should have a far greater practical sense than he has at present, due to the fact that his knowledge of physics, mathematics, mechanics and electrical phenomena, would have a foundation of practical mathematics. In the writer's experience with large numbers of the higher grade college students, he has found that nothing tends to develop their active thinking powers like practical or applied mathematics. This teaches them to think accurately and rigidly; it teaches them how to formulate general statements in concise form; it teaches them how to pass more directly from cause to effect; and it shows them how to pick out defects in their own reasoning and analysis, whether it be of a mathematical nature or otherwise. In other words, a good practical mathematician does not appear to be able to "fool himself" into thinking certain things are so or not so, as easily as is the case with other kinds of people. Again a mathematical mind, of a practical nature, has the ability for bridging across between apparently disconnected points and for obtaining short cuts to results, such as are not possible with other types of minds. This is why the writer argues so strongly for practical mathematics as a basis for true engineering. Men so trained possess tools which enable them to obtain quickly and accurately, results which others can only reach by roundabout methods as already said in other words.

In the proper engineering education, other lines of endeavor than mathematics are also needed, in order to broaden a man, but one essential ingredient is a broad fundamental training in practical mathematics, and without this it is hard to see how a high grade technical education is possible. Without this, schools may turn out *engineers in name*, as is so often the case, but *engineers in fact* cannot be turned out without a working knowledge of mathematics, which, as already said, is to a great extent the basis of all engineering. Therefore, let us put more work on this part of the foundation in order that the whole structure may be more substantial.

Education

BY S. E. DOANE
Fellow, A. I. E. E.
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The author points out that a college course should turn out men who have acquired habits of clear thinking, concentration, perception, observation, and decision. These men should have some knowledge of the details of the subject on which they plan to specialize in later life, but this knowledge is purely incidental and is acquired in illustrating the broad principles which are useful in all phases of engineering education. It doesn't really matter much on what a young man thinks he will specialize when he leaves school, if he has clearly in mind that the purpose of education is to train his mind to enable him to acquire as much fundamental knowledge as possible, and also to acquire an incidental knowledge of the specific applications of such fundamental knowledge.

The obvious point to the paper is that mental training is the principal thing, assuming, as a matter of course that physical and moral training are sufficient to physically support an active mind.

The man has well begun his education who has acquired the inclination and the ability for self study and development, and who graduates with the thought that he has merely begun a lifetime of self education. His college education has served its purpose if it has given him a good start.

The author suggests that the instructors in our colleges should be given an opportunity thoroughly to acquaint themselves with the industry for which they are training men by spending one year out of three in industry, the other two years to be spent in teaching.

THE chairman of the Educational Committee of this Institute, Professor Magnusson, has invited me to define my views on Engineering Education. He has suggested that, "if engineers would * * * frankly state their views on the training or lack of training given engineering students, and offer constructive suggestions for improving the college trained engineer, much of value might be gained."

During my thirty-five years in the electrical industry, it has been my privilege to know several hundred college men. Many of these came to work in my department directly upon their graduation. Practically every engineering school in the country contributed its quota. My long association with these men has led me to form certain opinions regarding the training they received, and the training which I think they should have received, which I shall attempt to outline in this paper.

The purpose of education is to cause the person who is being educated to acquire experience of others.

Generalities of the character which must be considered in a paper of this sort can only apply to men who are normal physically, morally and mentally. It is my observation that those who stand high in all these qualities will do best as engineers.

I would, therefore, if I had charge of the destinies of the average college, aim to so sift out my applicants that the majority of my students would be men above the average in these three fundamentals.

I would eliminate those who are weak in any one of

the three fundamental requirements without regard to their strength in other qualities. Mind you, I am talking now about the general engineering training. There are many men who are weak in body who can qualify for brilliancy of effort and become highly trained specialists. In my judgment, these men find no place in a standardized program. If I were considering how best to educate a particular individual who was weak in any one of the three, I would never advise him to take a general course of engineering. He might, however, become a great success in life in some highly specialized effort because of very superior mental attainment. Let us assume that we are training the average engineer and that he is well balanced physically, mentally and morally.

The college should perform six functions. It should offer directly:

1. Instruction in engineering knowledge. This might be subdivided into the teaching of
   a. Fundamentals
   b. Specific applications.
2. Instruction in non-engineering subjects, such as English, Economics, Law, etc.
3. Instruction and training in hygiene.

It should also make adequate provision for:

4. Inculcation of habits of clear thinking, concentration, persistence, observation, decision, imagination, etc.
5. Infusion of principles of fairness, unselfishness, tolerance, refinement, courtesy, etc.
6. Formation of friendships.

Obviously, no special courses to teach clear thinking, concentration, persistence, observation, decision, etc., can, or need, be given. It nevertheless appears to me that these qualities should be taught. This may seem paradoxical, but what I mean is this. Every instructor, in teaching a subject, knows that he is teaching more than just that one subject. He knows that he is also conveying lessons in perception, efficiency, decision, and so on, as a part of the more specific study. For example, in teaching drawing he emphasizes accuracy, neatness, observation, etc.

The point I want to make is that emphasis, during the regular course of study, should be placed upon the characteristics which contribute so largely to the future success or failure of an engineer. If the instructor will always bear in mind that he is teaching more than the facts or principles involved in a particular subject, he will do much to mould his students into efficient and productive contributors to the common good.

In addition to the "concurrent courses" in the class room, it would seem that a great opportunity exists to develop these qualities during physical training. It is apparent that many of the sports which are so popular in this country (and which I believe have contributed toward making the American what he is) are capable of developing these habits. Take tennis, for example. Tennis will develop promptness of decision, quickness of thought and concentration. Indeed, the game cannot be well played unless the player possesses these qualities to a marked degree.

Many of these things which have just been said also apply to the infusion of principles of fairness, unselfishness, tolerance, refinement, courtesy, etc. The instructor must stress these qualities at all times, but the greatest training will come, not from the instructor, but from contact with one's fellow students. It will also come indirectly from better developed minds and better developed bodies. It will come from the exercise of the qualities which were previously mentioned—observation, decision, concentration, etc. It is obvious that a man with a well developed sense of observation and perception will very easily learn what is proper in the way of courtesy, refinement, tolerance, etc. A man who can think clearly is not likely to be bigoted, or unfair.

The sixth value of a college education lies in the opportunity it offers for the formation of friendships. This needs no special reservation of time in the college curriculum. The constant association with fellow students, the common purpose, the similarlity of ideals and ambitions, a school spirit—all these go far toward making college friendships lasting and sincere.

We are now left with the problem of dividing the student's time and effort among engineering instruction, non-engineering instruction, and physical training.

My experience has led me to believe that a person's physical characteristics play a great part in what he can, and will, do. If they are good they serve as accelerators; if they are bad, they are handicaps.

It would seem to me that such time should be devoted to physical training, hygiene, etc., as would best meet the needs and requirements of the normal or average college man. This is a rather vague statement but I hesitate to make it more specific.

I do believe this, however, that more physical exercise, by a great many who are now in college, would result in great benefit. There are many students who are so intense in their desire to acquire knowledge that they cram their minds at the expense of developing their bodies.

Having allowed time for exercise and recreation, how much time should be allotted to non-engineering instruction and how much to engineering? How much of the latter should be devoted to fundamentals and how much to special applications?

Broadly speaking, I would say that the college man should have sufficient non-engineering training to enable him to express himself clearly (both orally and in writing); to give him a fair knowledge of economics—of the principles which govern our daily life; to offer him at least a speaking acquaintance with the laws by which we are governed in our relations with our fellows. He should be taught the principles of ordinary business, such as the rudiments of accounting, methods of computing costs, etc.

This may seem to be a large assignment, but such a program of non-engineering education should not be

allowed to consume very much time. It is not necessary to go into any of these subjects very deeply. It is sufficient to touch upon their more important features.

Some of this non-engineering education may be obtained in connection with the engineering courses. Clear expression and good composition should be as definitely required in written work on any engineering subject as knowledge of the subject itself.

The greatest problem in allotting time and effort among the various aims of the college engineering education arises in considering whether fundamentals, or specific applications, should be emphasized.

Some claim that a good knowledge of the fundamentals of a subject (though not necessarily the most thorough kind of knowledge), followed by a thorough training in typical applications of these fundamentals, will be of greatest benefit to the student. They claim that the knowledge of certain specific applications of the fundamentals in practise will enable the student, by analogy, to best meet his needs in later life.

Others, and I believe they are now in the majority, believe that a very thorough knowledge of the fundamentals involved in engineering practise, and less acquaintance with the applications which have been made thereof, would be preferable. This is my belief.

The stressing of application leads to specialization. No student really knows exactly what he will do after he leaves school. Those who specialize while in school may find themselves doing something entirely different within a short time of their graduation. As the result of specialization many discover that studies which they had neglected, because they did not consider them of practical value in the field they intended to enter, were really of the utmost importance and value in the field they really entered.

In reading over the suggestions summarized by the chairman of your committee, Professor Magnusson, it seems to me that many of us expect too much from the immature youths from our colleges.

In all of this summary the reply of Mr. Lamme is most directly parallel with my own judgment. It seems to me that there is only one of the three fundamental assets that we can hope to find fairly well rounded out. A man reaches physical maturity at an earlier age than he will reach either his moral or mental maturity.

He should be physically fit and should know how to keep himself fit when he graduates.

He should be well advanced toward his moral maturity and should be well grounded in his habits to the end that he will maintain a high moral standard.

His mental equipment will be the farthest from development. When he graduates I think he should have the following mental qualities:

He must know how to study and should face the fact that he must be a student, throughout the remainder of his life,

a. Of knowledge

b. Of mental technique.

Under "a" he must know the fundamental laws and statements of fact of physics and chemistry. The so-called laws which an engineer must learn are, many of them, beyond explanation and must be accepted as statements of fact. Quantitative ratios must be understood. For illustration, a man should know broadly the qualities of materials, ratios of speeds, and the values of time in the quantitative sense.

My feeling is that while specialization in college avails little and that to attempt to teach a man in college anything specific, such as to design generators or motors, is almost useless, at the same time the principles of design can be taught as illustrations of the use of fundamental laws. At the time the man is acquiring his acquaintance with a law he also is obtaining a useful and sufficient illustration of its application.

I believe all specialization should come after graduation.

It is my belief that it will be found to be impossible to so define courses of study that we shall feel that our problem has been solved without approaching it from quite another angle.

I think that we will ultimately agree that these courses must be laid out understandingly by the educators themselves. How can these men do this without some experiences similar to our own?

How can these instructors, these teachers who have had no practical experience, plan to teach their students the things which those students will most need after they leave college, the knowledge which will be of greatest value, the details which will be of most use? How can they train their students best to meet the problems they will encounter, and the obstacles they will have to overcome, after they leave school, if they do not have clear ideas as to the form and character which these problems and obstacles will assume?

Thoughts of this kind have led me to suggest to several of my friends, who are directing educational work in colleges, that we should take these college instructors into industry for a period of time.

There are laboratories—excellent laboratories—in many of our large industries throughout the country, and upon the staffs of these laboratories are to be found some of the most eminent scientists and engineers in their respective lines. They are constantly at work seeking to add to existing knowledge. They are making important discoveries.

The plan which I have in mind—which is in an unfinished form, and which I know can bear much development—is roughly this. I suggest that the instructors in our engineering schools spend one of every three years in industry. Place these men in the laboratories of our great industries, in their research departments, in their engineering departments, in their manufacturing departments, perhaps in their commerical departments.

Allow them to acquire an intimate knowledge of the application of fundamentals in every field. Acquaint them with the latest methods and means by

which these fundamentals are utilized in actual practise. Permit them to breathe the atmosphere in which their students will later have to work. Give them an opportunity to acquaint themselves with the actual requirements which will be expected of the college man. Introduce them to the general nature of the problems with which their students will have to deal.

If the instructor can learn all these things, I am quite sure that the men who are sent out from the engineering colleges will be benefited beyond measure.

As I think of this proposal, I can conceive that the National Lamp Works might be able to use one college instructor every year, who would obtain a thorough acquaintance with modern practise in electric lighting and allied fields while earning his salary at productive work.

At the end of three years the instructor, who has spent a year in the electric lighting industry, followed by two years of teaching, would be released to devote a year to some other industry related to the subject he teaches. Three years later he would go to still another industry, or branch of industry, and so on.

During all this time, the instructors will learn to view the subjects they teach from new angles. They will become better able to emphasize the importance of any particular phase that their industrial experience has shown them to be important. They will be able to observe their own work in more accurate perspective, and their results will be of correspondingly greater value.

It may be argued that an acquaintance with one particular industry once in three years will not enable all, or even most, instructors to keep up with modern practise in that industry. It is my thought, however, that the men who return from a year's experience in industry will convey their impressions, and will impart their new knoweldge to their colleagues.

The acquaintances which these instructors obtain during a year in business will continue throughout a life time. Through these they will maintain a very desirable contact with the field.

A procedure, such as the one I have so roughly outlined would probably have to be worked out over a period of years. As I have said, it requires consideration by those who are in intimate touch with the deficiencies which it is desired to remedy. Perhaps I am too optimistic of the results which it may accomplish. Possibly the same results may be obtained by other, and more desirable means.

In any event, my suggestion is offered for whatever it may be worth.

Principles of Engineering Education

BY PHILIP TORCHIO
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The college training should be directed to imparting to the students the fundamentals of all physical sciences. Elementary calculus and analytical geometry should form the ground work to equip the pupil with the tools for analytical study of the problems of engineering applications. Laboratory work and drawing serve to solidify the theoretical ideas. The sound study of a foreign language is of vital importance to broaden the education of an embryo engineer. Any course of study that disciplines the mind is beneficial to the student. Anything that is easy does not discipline.

IN the greatest task of educating the youths of the nation, elementary and preparatory schools labor under extreme difficulties in securing moderates success in disciplining the pupils' minds for concentrated work and independent investigation. The college is thereby handicapped but, in an engineering college, this deficiency should be easily made up if the technical subjects are properly taught, remembering that "Any course of study that disciplines the mind is beneficial to the student. Anything that is easy does not discipline."

The college cannot make engineers; it can only build the foundation on which the graduates will erect the structure of their careers. For a solid foundation, the young man should be thoroughly trained in the fundamental laws of physical sciences and the units of measurements and their equivalent relations. He should also be made familiar and conversant with the use of elementary calculus and analytical geometry as later applied in the study of mechanical, electrical, and other subjects in the curriculum of engineering courses. These should include the physical and mathematical analysis of elements of mechanical structures, thermo-dynamics, flow of water, air and steam, laws of motion of bodies, radiation, transmission and transformation of energy, electrical and magnetic phenomena, et cetera. "It is better to see one thing than to look at a hundred. It is better to conduct a student to the inner chamber of one fact than to take him on a trip seeing greater knowledge." The only fitting time for mastering these fundamentals is during the college years, when the mind is receptive and reposeful, and the aid of the teacher is at hand.

The laboratory work should be planned to give the pupil an insight of the theoretical facts applied to practise. For the same object, it may be beneficial that, in the drafting room, each student or group of graduating students should make to scale detail drawings of a different machine, with accompanying calculations of the important elements affecting its construction. Besides this machine drawing, each group

should make a detail project layout of an industrial installation for an assumed definite production or service, like a cotton mill with electric drive, a coal skip hoist, a mine mechanical equipment, an ice plant, a shoe factory, a power plant, a transmission line and substation, et cetera. The benefits accruing to the whole class from these different projects are great, not only for what each student absorbs and makes intimately his own from the close study of the details of his project, but also for what he learns by the interchange of thoughts and ideas with the other students who naturally fall into discussing with each other the features of their respective problems. Such discussions open their minds to widely different engineering problems and broaden their views in correlating the importance of these factors.

In addition to these studies, the pupil should pursue the study of a foreign language, like French, Italian or German, so that he can read and write it fluently, and possibly speak it with facility. I cannot emphasize these advantages too strongly. I do not know of a more broadening, instructive and inspiring education.

My conclusions are that "it is not so much knowing a whole lot as knowing a little and how to use it that counts." The greater the concentration and thoroughness with which the embryo engineers are trained in the fundamentals and their applications, the more self-reliant they will be made for practical life. I wish it to be understood that I do not aim to make engineers theorists, but I wish to instill in them broad and sound theory at the time and place when it can be done most efficiently. My idea is that a broad knowledge of the fundamentals of all physical sciences is the most liberal education with which a future engineer may be endowed.

Better Preparation of Students for Railway Work

With Special Reference to the Telegraph and Telephone Department

BY I. C. FORSHEE
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The more complicated communication systems, their use and importance on railroads, the extension of power transmission lines and electrification of railroads with the resultant effects upon the communication systems require that technical men, who preferably have been given special training that will qualify them to handle such problems, be employed in railroad telegraph and telephone departments. Many problems are in common with the large wire-using commercial companies but others are peculiar to communication systems on railroads.

On account of the great development of the methods and means of electrical communication in railroad work, the extensive and varied uses of such means, and the importance of having the service always available under widely varying conditions, it is becoming increasingly important that electrical engineers adequately trained in communication service be available in the telegraph and telephone departments of the railroads.

On many railroads the telegraph and telephone plant, which is very much larger than is realized by those not intimately informed, compares favorably with some of the large commercial wire-using companies. In such a system, extending as it does over hundreds and in many cases thousands of miles, there are problems that must be solved that are not encountered in the smaller plants. These problems involve an intimate technical knowledge of a specialized nature and many times require careful and extensive investigation and study to obtain the best solution.

While many of the graduates from the technical schools may be well informed in mathematics and fundamentals of physics, chemistry and applied electricity, all of which are essential, yet it is felt that if such institutions and the students contemplating such employment, were more familiar with the railroad communication problems there might be some advantages gained and time saved both by the technical graduates and railroads if there were included in the curricula more practicable applications of abstract theories and principles to concrete cases as met in this department. Many of our problems are common with the large wire-using commercial companies, but others are peculiar to the railroad systems.

It is believed that opportunities for men technically trained and who have specialized on communication work will be greater on the railroads in the future than they have been in the past, as the communication systems are rapidly becoming more complex, the problems of transmission more complicated, troubles from power interference and their solution more involved, and the possible applications of the recent developments more varied and important.

Among the various problems with which the department has to deal might be mentioned:

1. Construction of pole lines carrying open wires or cables or both.
2. Construction of conduit and cable systems.
3. Installation of telegraph and telephone equipment.

4. Telegraph and telephone transmission.
5. Design of circuits.
6. Specifications and tests for construction and maintenance material.
7. Electrolysis of underground structures.
8. Inductive interference.
9. Telegraph and telephone traffic.
10. Accounting and estimating.
11. Preservative treatment of woods and metals.
12. Radio and wire carrier systems.
13. Contracts and patents.
14. Electrical protection.
15. Wire testing, maintenance and service restoration.
16. Engineering research.

There are details associated with each of these items which are peculiar to the application on the railroads. Only general subjects are given and could be amplified appreciably, as will be obvious to one familiar with telegraph and telephone problems.

If more specific information is desired on any of the above subjects it can be obtained from the Secretary of the Telegraph and Telephone Section of the American Railway Association.

Training for Character

BY A. M. DUDLEY
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Some fundamental requirements in the character of a successful engineer as a man and as an engineer are outlined, together with considerations of the school and the instructor to produce and train such a character. Some ideal accomplishments to be attained are pointed out.

THE requirements for character in an engineer are two-fold, first as a man and second as an engineer. The motto which should hang before every worker in every line of work is this; "*First*, be a *man*", with the accent on the first and last words. The fundamental requirements for manhood in engineering are the same as for all professions and may briefly be touched upon as follows; absolute honesty, first with one's self and then with others; sincerity in one's work, remembering that whatever is worth doing is worth doing well; courage to put one's ideas across in the face of influential opposition and courage to accept the results of one's errors and build anew, courage to "keep your head when all about you are losing theirs and blaming it on you"; self control in all things, especially one's temper; self control of the ego, thereby keeping a sense of proportion as to one's real place in the world and preventing selfishness, tactlessness, discourtesy to others and a long train of ills; charity in judging men, recognizing that the heart and real intent are what count and not accidental circumstance; respect for the highest ideal of manhood and man's work in the world, based first, last and all the time on *service*—service to God, man and country.

The special requirements for character as an engineer might be sketched in this way; a fundamental sense of fairness, never letting one's judgment be warped by one's feelings; never distorting physical facts as shown by tests, to fit a theory instead of making the theory fit the facts; generosity in recognizing the good work of others and giving full credit to them and sharing their pleasure in it; recognition at all times of the commercial side of engineering, remembering that "an engineer is one who adapts the forces of nature to the uses of man" and that of two engineers who do the same job equally well from the viewpoint of physical results, he is the greatest who accomplishes it at the least outlay of money or physical resources; character to cooperate to the fullest extent with one's fellow workmen when joined with them to do a job, regardless of temperamental incompatibility or personal likes and dislikes; tenacity of purpose—never to be a "quitter" but to stick to it always and put the job across—*quickly* if possible but *surely* in any event; open mindedness to acknowledge personal error when plainly proved and to start anew without prejudice on the right basis.

To anyone considering this matter there will appear other and perhaps more essential qualities, but these are sufficient to show the necessity for a strong character in an engineer. The next question is how shall this character be trained. The two fundamental requirements are the right institution and the right instructor. No time will be taken here to discuss the relative merits of the exclusively technical school as against the college or university. Men of character graduate from both, and the humblest schools can claim alumni who shine as bright stars in the engineering firmament. But the ideals of the institution must be right. It must regard engineering as one of the learned professions, and as such must not be satisfied with any less degree of scholarly attainment in its engineering faculty than in its divinity or law or medical school. At the same time, since engineering is intensely practical, it should have on its faculty men who have made good themselves in the practise of the engineering profession, who, by their attainments as well as their ability can command doubly the respect of students. Since these specifications for instructors are high, the institution must be prepared and ready to pay a commensurate salary. It should not make the mistake now so regrettably common of employing a high grade man as instructor at a salary below his commercial value and expecting him to carry on a lucrative private

practise as a side issue so that he can afford the sacrifice of teaching.

One more thing that the institution should not do if it would preserve the respect necessary to inculcate character in the youth is to carry on commercial research or similar work where the facilities of the school become the source of private profit to outside individuals or to the investigator inside the school. Particularly is this true of institutions supported directly by the state. Wide open publicity as to the result of all investigations and payment made by the client to the school and by the school to the investigator is the only safe course to keep the atmosphere clear and conducive to the best ethical ideals which make for character.

As to the instructor, it is realized his personality and his attitude to his work are the greatest single element in the training of his students in all ways. One of our great men has said that his idea of a university was a log with a student sitting on one end and Mark Hopkins sitting on the other. To be a great success the instructor must be many things which are achieved only after a struggle with human nature. He must be unselfish and self sacrificing. He must be so sure that the building of men is the greatest profession in the world that he will be willing to accept his salary as a teacher and bend his entire energies toward becoming the best possible teacher of engineering. While he has himself practised engineering, he must limit his outside consulting work to an amount necessary to keep his hand in and to serve as texts for his lectures and laboratory work and not use it as a primary means of subsistence. He must be vitally interested in young men and interested in all their phases and problems, capable of advising on human questions of all sorts. He must establish a personal contact that exists beyond the class room and he must use that contact to instill the fundamentals of character while he instills the fundamentals of mathematics and other subjects in the curriculum.

If the school is right and the instructor is right and the student does his part, we shall have an outstanding race of engineers whose word is good as their bond, who bring to their work an enthusiasm that glorifies both the work and the worker, who accept praise and blame with a level head and a steady hand, who take suggestions and ideas from the humblest sources and develop them into real engineering, who give credit where credit is due, who carry their message to Garcia and hang on to the job till it's done, who worry more about the work they are doing than the pay they are getting, who know that a "man's a man for a' that and a' that," and whose personal conception of character blooms into two great requisites for human happiness—good health and the spirit of service.

Some Suggestions Concerning the College Education of an Engineer

BY CARL HERING
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The author considers the first requisite of college training to be a thorough drilling in the fundamentals in physics. A student who is well grounded in the fundamentals is in the best position subsequently to acquire a knowledge of details.

The student's most useful tool to work with is mathematics, but this should be taught to engineers by one who considers it an engineer's tool, and not a source of amusement. All the mathematical results should convey as clear a quantitative meaning to the engineer as numbers do when they represent an amount of money.

A third requisite is the use of mental exercises to develop mental strength. The student should be disciplined by mental exercises in the form of problems which should have some practical significance, so as to show the utility of the mental process, thereby developing interest.

Today is the era of specialists; even electrical engineering, as one subdivision of engineering, is again subdivided into so many branches that a student should either make a choice between them, at least in his last college year, or take a special post-graduate course. Different colleges would do well to specialize on different subjects, especially in their post-graduate courses. The writer has urged that at a time when a student must choose his vocation he has little knowledge of what his choice involves, and it is suggested that the regular college courses should include lectures describing the different vocations, the nature of the work involved in each of them, and the prospects of advancement, salaries, etc. Success in teaching can be measured by the interest that the teaching can develop in the minds of the students.

It is a mistake to keep the able students back to the level of the poorest in the class. The brightest students should be given every possible opportunity to advance.

THE college education of an engineer should be considered to be analogous to the foundations of a building on which a superstructure is subsequently to be erected, rather than to the superstructure. When a foundation is bed rock, it will support any superstructure that may later be decided upon.

The foundations of an engineering education are the fundamentals in physics, that is, the laws of nature concerning matter and energy in their various forms, just as the addition and multiplication tables are the foundations of arithmetic. A profound and thorough drilling in these fundamentals and how to use them should, therefore, be the first and most important requisite; they should be so thoroughly

grounded in the mind of the student that they become almost an intuition, involving little effort of mind to deal with them, and an almost instinctive revulsion against their violations. An intuition is well defined as "instinctive knowledge of the relations or consequences of ideas, facts, or actions." As in a building, the foundation is the least conspicuous part in the final product, but it is the part on which the stability of the whole superstructure depends. In a choice between the two, a student well grounded in the fundamentals but with less instruction in the superstructures like specialities, professor's hobbies, details and refinements, will unquestionably become a greater engineer than when the amounts of these two kinds of instruction are reversed. To one who is well grounded in the fundamentals the subsequent acquirement of the knowledge of details and refinements, even if after leaving college, will be a far easier matter than under the reverse conditions.

While these fundamentals are the most useful materials for his work, his most useful tool to work with is mathematics, not pure mathematics but applied mathematics. As a reliable means to arrive at a useful end quickly and directly, it is a most wonderful tool, generally a far better one than arithmetic, but its use as a mere means of entertainment should be left to the mathematicians. It should be taught to engineers by one who considers it an engineer's tool, a utility, and not a mere source of amusement. All numbers and their decimal points obtained mathematically should convey as clear a quantitative meaning to the engineer as they surely do when they represent an amount of money.

Another important factor in the education of an engineer is mental exercise to develop mental strength. When we lift a weight in the gymnasium it is not because there is any useful result in that weight being put on a higher level, but it is to strengthen our muscles. Similarly the mental strength of a student should be developed and disciplined by plenty of mental exercises, say in the form of problems, which should by all means have some practical significance so as to show the utility of the mental process, thereby developing interest; he should be taught to think and reason correctly and not merely have his memory crammed with words and facts as in the teaching of a monkey or parrot. A strong, well trained mind can subsequently absorb details with great ease, with the additional advantages that it can distinguish between the wheat and the chaff, and is not so easily misled. The great mass of engineering facts and data are better preserved in books of reference than in ones brain, which can be made better use of for correct reasoning. Generally a brain is not entirely a vacant space to be filled by college professors, but is rather like a muscle which is to be trained by them to do skilful work.

Knowledge has made such vast strides that in a four years' course it is today physically impossible to teach and mentally impossible to learn, all that it would be of benefit to know. The present is the era of specialists; a Jack of all trades is a master of none; better let a trained financier do the financing, a trained engineer the constructing and a trained salesman the selling. It is imperative, therefore, to make a choice; in general the first choice in an education is that between utility and what might be called polish or ornamental education. Formerly, and in some colleges of today, particularly those for girls, the latter is the main goal. Having chosen utility the next choice is between science and the other learned and useful professions; science and financiering do not always mix well, their standards of morals sometimes differ. In science there are many further subdivisions one of which is engineering, which again is subdivided into branches. Even electrical engineering, as one of these, has so many subdivisions which have little more than the fundamentals in common, that a student ought to make a choice between them, at least in the last year, or take a special post-graduate course. Different colleges would do well to specialize on different subjects, especially in their post-graduate courses, which should then be directed by specialists.

Having decided on any one particular vocational training, the choice of the particular subjects to study should be decided solely and only on the ground of utility. In an electrical engineering course for instance there is so much more to learn than could possibly be crammed into four years, especially when there is an excessive and time robbing indulgence in athletics, that the student is deprived of much useful instruction and training if he has to devote a lot of this valuable time to such things as the dead languages, bible history, literature, etc. The proper use of the English language should have been taught in the preparatory schools.

The subsequent failures of college trained men have frequently been due to a mistake in the selection of their course in college. Other conditions being equal, the best choice is unquestionably the subject in which he is most interested. But in most cases at the time he has to make the choice he has no proper knowledge of what a particular career involves; the fact that as a little boy he enjoyed playing with toy electric railways does not, as some fond parents think, mean that he will make a good electric railway engineer. The writer has, therefore, often urged that at the time when the student must make a choice, a part of the regular course should be a few lectures describing what the various vocations involve, what subjects he will have to agree to study in each one, what the nature of the work will be and what the prospects are of employment, advancement and salaries. Such lectures would unquestionably greatly reduce the deplorable number of misfits and the great loss of time in later changing from one course to another.

The province of a physicist is to discover and formulate the laws of nature regarding matter and energy

while the province of the engineer is then to apply these laws for the benefit of mankind. Another definition of an engineer in popular terms is that he is one who can show how a thing can be done for one dollar that any fool can do for two dollars; a complementary definition of an administrator, or organizer, at least of some of them, then is that he is one who can get two dollars for something worth only one. In recent times, so many engineers have abandoned the true profession of engineering, that of designers and constructors, and have become administrators, organizers, financiers, or salesmen, for which positions their engineering training has undoubtedly helped them greatly, that these and many others, like the handling of labor, have recently often been included under engineering, a noble name to conjure with. Larger salaries and less interest in engineering, are generally the incentives for the change; some adminstrators can vote themselves their own salaries. But whether this modern use of the term engineering is desirable or not, it is true that an engineering training is of great value in such positions, and that, therefore, students should be told about these vocational possibilities and if they choose them they should be given a somewhat different course omitting certain studies and substituting others.

In the writer's opinion, success in teaching can be properly measured by the interest that the teacher can develop in the mind of the student. There are, of course, some very necessary studies that are without any interest, and, therefore, pure drudgery, like learning the multiplication tables, rules, terms, relations, formulas, etc, but aside from such cases of mere memorizing of some necessities, when a teacher cannot awaken the student's interest either the student is hopeless and should leave college, or else that teacher has not mastered the real art of teaching. Often have students told the writer how greatly they were interested in a certain subject, adding the significant clause that they liked that particular teacher, as he made it so clear; in the reverse case it may be the fault of either or both.

A serious error in many colleges, which might even be called an educational crime, is to keep the bright and able students back to the level of the poorest in a class. It should be the duty of every teacher to give the brighter students every possible opportunity to advance. The deficient ones should either be helped to catch up or made to repeat the previous year's work.

Students naturally take a delight in pointing out errors in what their teacher has taught them; finding such errors also tends to shake their confidence in other things he taught them, which is fatal; they also lose interest and respect when they find there is a simple, easily understood way of explaining something which they had been taught in a complicated, confusing way which was difficult to understand and hard to retain. It is therefore of the greatest importance for the teachers to be absolutely sure of the correctness of what they teach and to keep abreast with the times in their interpretations and explanations. It is, for instance, an intellectual crime, which might do much harm, to teach that a law is universal after it has been shown that it is not. The writer has been surprised to see the strong opposition of some teachers to modify their teachings of a year before in accordance with developments during that time.

What constitutes success in a career is variously defined and is a matter of opinion. Some measure it by the ratio of the money received to the time and effort spent, that is, the present labor union idea of doing the least work for the most money. According to that scale one who loots a bank is at the head of the list of the successful; there is a wide difference of opinion as to what is and what is not honorable; when the looting is done by a teller, he is a criminal, but when done by the president he is an expert financier. Others think that success is measured by the kind of service rendered or by doing something that is of some lasting benefit to mankind and to the world, such as the products of the researches of scientists, the discovery or development or invention of something useful, or erecting great and useful structures. Students have their choice, some look only for the dollar, others for something higher; the choice of their college course depends somewhat on this; many persons have made much money without having had a college course, but today the so-called self-made engineer who has not had a higher education and has not made up for it later, is hopelessly handicapped as an engineer in competition with those who have.

The engineer deals with the laws of nature, which govern him; nature is mercilessly strict in insisting on their enforcement to the letter; such a training therefor, tends to develop a respect for laws, an instinctive effort to do only what is right and to abhor what is wrong. He cannot cover up his faults or ignorance as doctors, lawyers, financiers and ministers can, and he must therefore be better trained. An engineering training is therefore also ethical in its effect.

SWEDISH WIRELESS STATION

In 1920 the Swedish Government appropriated 2,000,000 crowns for the establishment of wireless telegraph communication between Sweden and the United States. Negotiations were entered into with an American company, but up to March, 1921, they had not led to any agreement. On account of this fact and the general business depression, the matter was not presented to the 1921 Riksdag. The question has now been brought before the Government again in a note from the Telegraph Administration, with the intention of requesting permission to use the 2,000,000 crowns previously appropriated in order to proceed with the proposition.

Rating of Cables in Relation to Voltage

SUMMARIZED HISTORY OF PUBLISHED KNOWLEDGE BEARING UPON THE PERFORMANCE OF INSULATION UNDER ELECTRIC STRESS

Prepared by the Subcommittee on Wires and Cables of the Standards Committee

Introduction

UNDER the auspices of the Wires and Cables Subcommittee of the Standards Committee of the Institute, a symposium on the rating of cables with reference to heating due to conductor losses only, was held during the 1921 Midwinter Convention of the Institute with the object of checking the Institute's standards in regard to permissible operating temperatures for cable insulation. That is, the discussion was limited to the matter of the safe maximum operating temperature of low-voltage cables with negligible dielectric losses.

The six papers presented and the discussion thereon did not show any general agreement on the point at issue. In fact, the divergence of views was still just about as great as had been previously suspected, judging from views expressed informally in committees and elsewhere. The great importance of the subject was, however, emphasized and the need for sufficient comprehensive research work to establish the fundamental physical facts involved was made evident. The result has been the inauguration of a comprehensive research on this and other fundamental cable problems by the Research Department of the Massachusetts Institute of Technology under the auspices of the Paper-Insulated-Cable Research Committee, which is a sub-committee of the A. I. E. E. Transmission and Distribution Committee, the N. E. L.A. Underground Systems Committee and the A. E. I. C. Committee on Electricity Distribution and Use.

It is believed that a similar situation exists with reference to the rating of cables with respect to voltage and the Subcommittee on Wires and Cables of the Standards Committee has therefore arranged this symposium on the rating of cables with respect to voltage only, which will be a corollary of the symposium held last year on cables with respect to heating only (*i. e.*, current only). It is further believed that a discussion of the matter at this time is particularly timely, both because of a demand for the standardization of insulation thickness for impregnated paper cables and because of the many proposals under consideration for cables to operate at much higher voltages than any now in extensive use. It is hoped that the papers presented and the discussion thereon will enable cable engineers to more efficiently design and operate cables and thereby utilize more effectively the investment which the cables represent.

To be presented at the Annual Convention of the A. I. E. E., Niagara Falls, Ontario, June 26-30, 1922.

CONTENTS

I. Geometric Relations which Affect Dielectric Stress.

Jona, E. (*Trans. Int. Elect. Cong.* 1904, vol. 2, p. 550) showed that the electric stress in a dielectric between two concentric conducting cylinders, which is the simplest geometric representation of a single-conductor cable, follows the law.

$$H = \frac{E}{x \log \epsilon \frac{R}{r}}$$

where

H = stress in kv. per cm. at any point x cm. from the axis
E = difference of potentials between cylinders, in kv.
R = radius of outer cylinder, cm.
r = radius of inner cylinder, cm.

Levi, Civita, (*Rendiconti Circolo Matematico di Palermo*, vol. XX, 1905, part 1, p. 173) gives formula for maximum stress including the effect of stranding.

Thornton, W. M. and Williams, O. J. (*Electrician* 1909, vol. 63, p. 833) gave experimentally-determined diagrams of electrostatic force both for round and sector triplex cables.

Deutsch, W. (*E. T. Z.* 1911, vol. 32, p. 1175) derives approximate formula for the maximum stress including the effect of stranding.

Gorgas, Benischke, Petersen Etc. (*E. T. Z.* 1913, vol. 34, pp. 637, 783, 984, 1186, 1354) correspondence and discussion of stress at conductor surface, especially on approximate formula for stresses between parallel cylinders.

Middleton, W. I. and Dawes, C. L. (Trans. A. I. E. E. 1914, vol. 33, p. 1185) discussed the logarithmic formula, and showed that the stress at the surface of a conductor was a minimum when $d = D/2.72$, where d is the diameter over the conductor, D is the diameter over the insulation, and 2.72 is the Naperian logarithmic base e. There is also a discussion of overstressing of cables.

Russell, A., (*Proc. Phys. Soc.* London, 1919, vol. 33, p. 111) derives formula for stress between parallel cylinders.

Atkinson, R. W., (Trans. A. I. E. E. 1919, vol. 38-2, p. 971) developed a method of estimating the stresses in a triplex cable.

Del Mar, W. A. (Trans. A. I. E. E. 1919, vol. 38-2, p. 1018) gave diagrams of equipotential and stress lines in round and sector triplex cables.

Davis and Simons (Journ. A. I. E. E. Jan, 1921, p. 12) published tables of maximum stresses based on Atkinson's method.

Emanueli, Luigi (*L'Eletrotecnica* 1921, vol. 8, p. 573) gives experimental determinations of stresses in three conductor cables.

II. Dielectric Failure of Air.

Steinmetz, C. P. (Trans. A. I. E. E. 1893, vol. 15, p. 281) suggested that the diameter of a corona in air is such that the corona reduces the electric intensity (or potential gradient) at its boundary, to the constant value of the electric strength of air.

Ryan, H. J. (Trans. A. I. E. E. 1904, vol. 21, p. 275) found

that the apparent dielectric strength of air around a wire varies with the diameter of the wire.

JONA, E. (*Trans. Int. Elect. Cong.* 1904, vol. 2, p. 550) said that the diameter of the air corona, for a given arrangement of conductors, is independent of the size of wire and depends only on the voltage.

TOWNSEND, J. S. (*Trans. Int. Elect. Cong.* St. Louis 1904, vol. 1, p. 106) said that free ions exist in air which are accelerated in their motion when subjected to electric stress. When they attain a certain speed, they knock electrons from their atomic orbits thus liberating the electrons and converting the atoms into ions.

WHITEHEAD, J. B. (TRANS. A. I. E. E. 1910, vol. 29-2, p. 1183) said that as the logarithmic law for concentric cylinders indicates different stresses at a given distance from the axis, with different conductor diameters and as corona observations indicate the same stress, the logarithmic law must fail when corona is present and therefore the air carrying a corona must have a relatively high conductivity.

HAYDEN, J. R. AND STEINMETZ, C. P. (TRANS. A. I. E. E. 1910, vol. 29-2, p. 1125) showed that the disruptive discharge through a dielectric requires not merely a sufficiently high voltage, but also a definite minimum amount of energy.

WHITEHEAD, J. B. (TRANS. A. I. E. E. 1910, vol. 29-2, p. 1159) said that an electron requires an intensity of 170 kv. per cm. to give it sufficient velocity to break up a molecule by collision, and concluded from this that the ionizing agents, in the ionization by collision which creates corona, must be of atomic or molecular dimensions. Such ions require only 30 to 40 kv. per cm. He showed that there is no dielectric loss in air until the corona point is reached, that the electric strength of air is independent of the material of the electrode, that the corona voltage is lowered by surface impurities, that the corona has high conductivity, and that most of the dielectric loss takes place beyond it.

RYAN, H. J. (TRANS. A. I. E. E. 1911, vol. 30-1, p.1) applied th electron theory to the explanation of corona loss.

WHITEHEAD, J. B. (TRANS. A. I. E. E. 1911, vol. 30-3, pp. 1883-1885) gave evidence that corona is due to the liberation of ions from neutral molecules when the latter suffer collision with free ions moving under the impulse of an electric field.

PEEK, F. W. (TRANS. A. I. E. E. 1911, vol. 30-3, p. 1889) showed that the corona loss around a wire varies as the square of the excess voltage above the voltage at which corona starts. He also showed that the electric strength of air is about 30 kv. per cm. and that corona starts when this intensity is attained at a distance of 0.301 $\sqrt{r}$ cm. from the surface of the conductor. This distance is called the energy distance. A finite thickness of air must be under a stress of 30 kv. per cm. or more before breakdown occurs.

PEEK, F. W. (TRANS. A. I. E. E. 1912, vol. 31-1, p. 1051) showed that the energy distance for corona around cylindrical wires varies with the relative air density s and is.

$$0.301 \sqrt{\frac{r}{s}} \text{ cm.}$$

PEEK, F. W. (TRANS. A. I. E. E. 1913, vol. 32-2, p. 1767) showed that the energy distance for spheres is

$$0.54 \sqrt{\frac{r}{s}}$$

and that where the electrodes are placed closer together than the energy distance, the apparent dielectric strength increases.

PEEK, F. W. (TRANS. A. I. E. E. 1915, vol. 34-2, p. 1857) showed that the time lag of breakdown is conveniently measured in micro-seconds, and that the lag varies with the electrode and is a maximum for the needle gap and a minimum for a uniform field or for a sphere gap.

WHITEHEAD, J. B. AND BROWN, W. S. (TRANS. A. I. E. E. 1917, vol. 36, p. 169) showed that corona appears at a lower value when the wire is positive than when negative, the maximum excess of negative over positive (which occurred for small diameters) being 6.3 per cent. The values for alternating current coincide with those for negative continuous voltage. Evidences in favor of Townsend's theory of ionization by collision are given.

PEEK, F. W. (Dielectric Phenomena, p.84) says that air between concentric cylindrical electrodes has its maximum electric strength when the diameter ratio is 3 instead of 2.72, the value to be expected if the logarithmic formula were strictly applicable. This he deduces from the energy-distance and checks experimentally.

PEEK, F. W. (Dielectric Phenomena, p. 85) says that the corona in air seems in effect to be either a series resistance or it grades or distributes the flux density when the conductor configuration is such that corona occurs before spark-over. He said that under this condition spark-over between concentric cylinders, does not occur when $\frac{R}{r_1}$ = critical ratio, where r_1 = radius of corona, and R = radius of outer cylinder.

III. Ionization of Gas in Solid Insulation

FESSENDEN, R. F. in 1898 made experiments which showed the danger of air bubbles in solid insulation.

PERRINE, F. A. C. (TRANS. A. I. E. E. 1902, vol. 19, p. 1067) said that the failure of cable insulation is sometimes due to the presence of spaces filled with rarefied gases.

PETERSEN, W. (*Archiv. fur Elektrotechnik*, 1912, vol. 1, p. 28) called attention to the fact that air films in a dielectric of specific capacity K, are subjected to a stress of K times that in the surrounding medium, and that ionization may therefore occur therein at comparatively low voltages. He also said that ions are shot from these films into the surrounding medium.

DUBSKY, F. (TRANS. A. I. E. E. 1919, vol. 38-1, p. 537) measured the dielectric strength of thin air films between glass plates. He then applied these data theoretically to assumed gas spaces in solid dielectrics and showed the possible conditions under which ionization was likely to occur.

SHANKLIN, G. B. AND MATSON, J. J. (TRANS. A. I. E. E. 1919, vol. 38-1, p. 489) measured the ionization voltage in actual insulation designs by the dielectric loss method. In the case of coil insulation, such as varnished cambric and mica-paper, they give evidence showing that ionization not only occurs in the entrapped gas spaces but that it can cause serious damage. In the case of paper-cables, evidence is given showing that a true ionization occurs. However, the exact nature of this ionization, its position, and the possibilities of serious damage are not clearly shown.

IV. Dielectric Failure of Transformer Oil

TOBEY, H. W. (TRANS. A. I. E. E. 1910, vol. 29, p. 1189) after discussing generally the testing of oils for dielectric strength, gives particulars of the influence of moisture on this property.

HENDRICKS, A. B. (TRANS. A. I. E. E. 1911, vol. 30-1, p. 167) showed that moisture has an important effect in reducing the dielectric strength of insulating materials. In the case of transformer oil, if E be the kilovolts producing breakdown between 0.5 in. discs, 0.2 in. apart, and x = parts of water in 10,000, by volume, then

$$E = \frac{19.2}{x^{0.284}}$$

HENDRICKS, A. B. (TRANS. A. I. E. E. 1911, vol. 30-3, p. 1975) stated that transformer oil between concentric cylindrical electrodes has its maximum electric strength when the diameter ratio is about 7 instead of 2.72, the value to be expected if the logarithmic formula were applicable. He also said that the dielectric strength of transformer oil is increased by mechanical pressure, an increase from 0 to 200 lb. per sq. in. increasing the dielectric strength 50 per cent. This, by the electron theory, is due to the decreased mobility of the ions under pressure.

Peek, F. W. (*General Electric Review*, Aug. 1915, vol. 18, p. 821) states that a phenomenon similar to corona in gases also takes place in liquid insulations, such as oil, due to tearing apart of the molecules of the oil or occluded gases. It seems that occluded gases often take an important part in supplying initial ionization. The effect of moisture is also pointed out.

Peek, F. W. (Trans. A. I. E. E. 1915, vol. 34-2, p. 1857) found that the time lag is much greater for oil than for air.

Hirobe, T. Ogawa, W., and Kubo, S. (*Report*, Electrochemical Laboratory Tokio, Japan, 1916, report No. 25-3) showed that dust and fibrous matter in oil impair its insulating power, and that moisture has but little effect without absorbing media.

Peek, F. W. (Dielectric Phenomena, 1920) showed that the dielectric strength of transformer oil can be increased by the use of baffles which confine the motion of the ions, impurities, etc.

Peek, F. W. (Dielectric Phenomena, 1920) showed that transformer oil under electric stress exhibits properties similar to air. He showed that the energy distance is about $1.2\sqrt{r}$ cm. *i.e.*, about four times that of air, and that with such an energy distance, corona and spark-over voltages wil be equal for ratios of $\frac{R}{r}$ up to at least 300.

Hayden, J. L. R. and Eddy, W. N. (Jour. A. I. E. E., Feb. 1922) show how the failure of transformer oil depends upon the presence of impurities. They compare the number of failures at each voltage with the number to be expected according to the curve of probability, and find that they do not agree.

V. Electric Properties of Petrolatum.

Malcles, L. (*Comptes Rendus* 1910, vol. 151, p. 63) furnished the idea that the behavior of petrolatum in an electric field is the result of free ions which are mobile when the petrolatum is fluid and immobile when it is jelly.

VI. Residual Charge, Power Factor and Associated Effects.

Faraday, M. (Experimental Researches in Electricity, 1839) was probably the first to notice the phenomenon of residual charge.

Hopkinson, J. (*Phil. Trans.* 1877, vol. 167, p. 599) showed that the residual charge is proportional to the exciting charge and gives results on experiments performed on several kinds of glasses, showing the effects of temperature. He noted that the residual charge in a Leyden jar can be promoted by tapping the dielectric, an indication that such charges are due to some internal polarization which is affected by shock.

Ayrton, W. E. and Perry, J. (*Proc. Royal Society* 1878, vol. 27, p. 238) said that dielectrics exhibit an increase of strain under a prolonged constant dielectric stress and said that this was due to the "viscosity of the dielectric". They explained viscosity on the basis of the presence of comparatively conducting particles in "dielectrics of heterogeneous composition" and suggested that dielectrics and metals might owe their different properties to the presence of rotary molecular motion in the one and motion of translation in the other.

Muraoka, H. (*Wied. Ann.* 1890, vol. 40, p. 329) found that while paraffin and xylol showed practically no residual charge when separate, a layer of xylol on a layer of paraffin showed residual charge.

Maxwell, J. C. (A Treatise on Elec. and Mag. 2nd ed. 1881, vol. 1, chap 10, p. 412) proved theoretically that a compound dielectric built up of layers of different non-absorptive dielectrics would exhibit both absorption and residual charge effect provided that the product $\rho\, k$ is different for each lamina. (ρ = resistivity and k = specific capacity.

Steinmetz, C. P. (*Elec. Eng.* 1892, vol. 13, p. 272) showed that the energy consumed by a dielectric medium under alternating electrostatic strain is directly proportional to the square of the intensity of the electrostatic strain or $H = k\, E^2$. Hence, whereas magnetic hysteresis follows the law of the 1.6th power, dielectric hysteresis follows the law of the square, that is, it acts just the same as a mere dead resistance connected into the circuit.

Bedell, F. and Kingsley, C. (*Phys. Rev.* 1894, vol. 2, p. 170) showed by the use of curves, the effects of a previous negative charge upon successive residual discharges, he effect of absorption upon the discharge curves, the effects of temperature on the resistance of oils and solid dielectrics.

Steinmetz, C. P. (*Elec. World* 1901, vol. 37, p. 1065) cited experiments on a paraffined paper condenser, showing that the dielectric loss is proportional to the square of the voltage and practically independent of the frequency. He suggested that the loss was largely due to mechanical motion of occluded air molecules under the influence of the alternating stress.

Drysdale, C. V. (*Electrician* 1901, vol. 46, p. 890) gave data on dielectric loss in cables and condensers, and called attention to its importance due to the energy loss being a continuing one regardless of the load. He also gave tables of losses in dielectrics, power factors, etc., for different types of mica condensers with varying pressures.

Torchio, Philip (*Trans. A. I. E. Cos.* 1902, pp 217-219, quoted in Trans. A. I. E. E. 1917, vol. 36 pp. 499-501) gave results of measurements of dielectric losses on long feeder cables installed, and stated that "the dielectric losses are approximately proportional to the frequency, to the square of the voltage and to a certain function of the temperature not yet determined. The temperature however, increases considerably the dielectric losses."

Skinner, C. E. (Trans. A. I. E. E. 1902, vol. 19, p. 1047) showed that dielectric loss varies with frequency, but not always in direct proportion. The variation from proportionality was especially marked at higher temperatures. He also showed that not only is the loss greater at high temperatures, but so is the rate of increase of loss.

Perrine, F. A. C. (Trans. A. I. E. E. 1902, vol. 19, p. 1067) said that work with cables has shown that a slight amount of moisture in the insulation will materially increase the heating and that heating of this character almost invariably results in final breakdown.

Monasch, B. (*Annalen d. Physik* 1907, vol. 22, p. 905) says that the loss varies strictly as the square of the impressed voltage up to the point of formation of corona and that in cables at ordinary frequencies, the loss is approximately proportional to the frequency.

Fisher, H. W. (Trans. A. I. E. E. 1907, vol. 26-2, p. 997) gave data on the dielectric loss in rubber compounds and showed that compounds containing a large amount of extractive matter may have lower losses than those containing small amounts.

Trauton, F. T. and Russ, S. (*Proc. Royal Soc.* 1907, vol. 20, p. 551) showed experimentally that the recovered (residual) charge does not follow an exponential law as derived by Maxwell, but a logarithmic law.

Shuddemagen, C. L. B. (*Prov. Am. Acad. of Arts & Sci.*, 1909, vol. 44, p. 467) showed that the current which forms residual charge, or in other words, the absorption current, is far from negligible when the charging interval is very small.

Hochstaedter, M. (*Elek. Zeit.* 1910, vol. 31, p. 467) reported that tests on impregnated paper cables showed the dielectric loss to be exactly proportional to the frequency. He found that the maximum voltage in each cycle occurs simultaneously with the zero value of the current, but the maximum current does not coincide with zero voltage. He made a "dielectric hysteresis loop" from oscillograms and deduced therefrom the capacity, residual charge and dielectric loss.

Decombre, L. (*Comptes Rendus*, 1911, vol. 152, pp. 315 and 1755) discusses dielectric loss in relation to polarization and makes some developments of Maxwell's theory. His reasoning, which is typical of that of several other physicists, is as follows:

The charge in a condenser is made up of two parts, one $k\, E$,

due to an ether displacement and the other m, to a polarization of the dielectric, or $q = m + k E$. According to the theory of Lorentz,

$$a \frac{d^2 m}{d t^2} + C \frac{d m}{d t} + b m = E$$

where a, b, and c are positive coefficients. If the voltage E is alternating the term $\frac{d^2 m}{d t^2}$ which is proportional to f^2, where f is the frequency is negligible, unless the frequency is of the order of that of light. Hence

$$c \frac{d m}{d t} + b m = E$$

But the energy absorbed is $E\, d\, q$, i. e., $E\, (d\, m + k\, d\, E)$. For a complete period the energy lost, if assumed to be dependent on the polarization of the dielectric, therefore equals

$$\int_0^T E \; d\, m \text{ or } \int_0^T c \left(\frac{d m}{d t}\right)^2 d t$$

Hence, the alternate charge or discharge of a condenser causes a dissipation of energy proportional to the square of the polarization current, $\frac{d m}{d t}$.

Rayner, E. H. (*Jour. I. E. E.* 1912, vol. 49, p. 3) reported the results of an extended investigation to determine the relative effects of a short application of high test voltage or longer application of lower test voltage. He also gave considerable information about the effect of humidity and temperature on the dielectric strength of insulating materials. The paper has a bibliography on the subject of dielectrics, containing 300 references, dated from 1864 to 1912.

Walker, Miles (*Jour. I. E. E.* 1912, vol. 49, p. 71) showed that if curves be made with temperature for abscissas and watts for ordinates, one curve giving the power lost in the cable and the other the power dissipated, an increase of temperature will be cumulative if the dissipation curve is above the loss curve, and non-cumulative if the reverse is true.

Fleming, J. A. and Dyke, G. B. (*Jour. I. E. E.* 1912, vol. 49, p. 323) showed that two non-absorptive condensers of different capacities, each in series with a non-inductive resistance and the two connected in parallel, will act as a single condenser having absorption, if the products $c_1 r_1$ and $c_2 r_2$ are unequal. This paper and the discussion thereon, give a clear theoretical treatment of the subject and considerable experimental data to support the theory.

Addenbrooke, G. L. (*Electrician*, 1912, vol. 68, p. 829) showed by measurements at different frequencies that dielectrics may be considered to consist neither of capacities and resistances in series nor of capacities and resistances in parallel. He also showed that the loss in liquid dielectrics is independent of the frequency above a certain point whereas in solids it increases with the frequency, but not always according to a linear law.

Pungs, L. (*Archiv. f. Elektrotechnik* 1912, vol. 1, p. 329) showed that the dielectric losses in transformer oil are practically independent of the frequency. He concluded from this that the losses are due to ionic conduction rather than hysteresis. Resin oil showed similar properties the loss increasing but slightly with the frequency.

Addenbrooke, G. L. (*Electrician* 1913, vol. LXX, p. 673) gives data on dielectric loss in gutta-percha. He found the power factor to vary as follows with frequency.

Cycles	Power Factor Per Cent
46	4.0
12	5.5
6	6.3
3	7.2
1.5	7.5

Wagner, K. W. (*Ann. der Phys.* 1913, vol. 40, p. 817, and *Elek. Zeit.* 1913, vol 34, p. 1279, developed Maxwell's theory of residual charges arriving like Maxwell, and unlike Trauton and Russ, at an exponential equation for residual charge current. He showed that his theory is consistent with observed facts regarding the relation between power factor and frequency. He also showed that his theory leads to the possibility of more than one maximum of dielectric loss at various temperatures, this also being in accordance with observed facts.

Evershed, S. (*Jour. of I. E. E.* 1914, vol. 52, p. 51) says that in absorbent insulators the conduction is not normally through continuous filaments of moisture but by endosmose. He explains endosmose as a motion of films of water along the walls of an insulator due to the water being electropositive to practically all solid insulating materials and being therefore drawn through the pores of the solid toward its electronegative end, where a potential gradient is impressed on the solid. He explains the well-known time fall of insulation resistivity as being due to the spreading of moisture globules over internal surfaces of the solid insulation under the influence of endosmose, *i. e.*, normally the moisture exists in globules separated by dry internal labyrinth surfaces of solid, but when a potential gradient is applied, these globules spread over the surfaces of the labyrinth and reduce the resistance. When the potential gradient is removed, the films coalesce into globules causing the resistivity to rise. Under the influence of an alternating potential gradient, the globules do not have time to spread over the surfaces, but vibrate, causing a loss of energy. Evershed made a model insulator consisting of an inverted *V*-tube containing alternate drops of water and air, the ends of the tube being each set in a beaker. When a potential gradient was established between beakers, the drops of water spread along the walls of the glass tube, and the resistance characteristics were found to be similar to those of an absorbent insulator. When the potential gradient was raised, failure began in the form of sparking along the films from one drop to another.

Wagner, K. W. (*Elek. Zeit.* 1915, vol. 36, p. 111) developing Maxwell's theory of composite dielectrics shows by simple calculations that in a dielectric composed of two elements, one of which has resistivity r and specific capacity k and the other resistivity R and specific capacity K, the residual charge will be zero if $r\, k = R\, K$. He also suggested that the dielectric loss would be zero under these conditions.

Skinner, C. E. (*Jour. Franklin Inst.* 1917, vol. 183, p. 667) showed that the dielectric loss in transformer insulation follows the equation $W = k\, E^n$ where the constants have the following values:

Temperature Deg. Cent.	k	n
30	0.025	2.34
40	0.032	2.27
50	0.044	2.22
60	0.068	2.21
70	0.107	2.18
80	0.155	2.15

W = Watts lost and E = effective kilovolts.

Bang, A. F. and Louis, H. C. (Trans. A. I. E. E. 1917, vol. 36, p. 431) following the method suggested by Walker, developed a method of determining the influence of dielectric losses on the rating of cables. They determined dielectric losses by the heating effects and gave data on the emissivity of conduit lines.

Clark, W. S. and Shanklin, G. B. (Trans. A. I. E. E. 1917, vol. 36, p. 447) give formulas for calculating dielectric loss in three-phase cables, data on dielectric losses, resistivities and specific capacities. They showed that when an impregnated paper cable is bent, voids are created which become filled with gases from the volatilization of the oils, pp. 458–460. These

reduce the resistivity at high voltages due to the ionization of the gases. A comparison of losses in old and new cables is given.

Atkinson, R. W. (Trans. A. I. E. E. 1917, vol. 36, p. 521) says that tests on impregnated paper cables at 25 and 60 cycles showed that the loss at 25 cycles is always somewhat less than at 60 cycles, and in some cases, is in almost direct ratio with the frequency. In other cases, there is little difference. Tests on a dried but unimpregnated paper lead cable showed the dielectric loss to be extremely low at all temperatures.

Swyngedauw, R. (*Revue Gen. d'Elec.* 1919, vol. 5, p. 283) said that tests on triplex cables indicate that the dielectric loss obeys the following law:

$$W = (a + b\,E)\,f\,C\,E^2$$

where a and b are constants, C is the capacity, f the frequency and E the voltage.

VII. Grading of Insulation

Jona, E. (1898) made graded cables and exhibited them at Milan.

O'Gorman, M. (*Journal I. E. E.* 1901, vol. 30, p. 608) showed that to get uniform stress in a dielectric, the product $K\,x$ must be constant where K is specific capacity and x = radial distance from the axis of the cable.

Morris, J. P. (*Jour. I. E. E.* 1907, vol. 40, p. 50) claims to have first suggested the use of intersheaths in the cable installation, in order to anchor the potential of the various layers of insulation in any manner desired by means of connections outside of the cable.

Russell, A. (*Jour. I. E. E.* 1907, vol. 40, p. 7, and *Electrician* 1907, vol. 60, p. 160) said that when a dielectric under stress breaks down, a disruptive discharge ensues only when the effect of this partial breakdown is to increase the electric stress on the remaining portion. He also pointed out that in a composite dielectric subjected to alternating pressures, the voltages across the layers are usually out of phase with one another, and therefore that across each layer may be greater than indicated only by the thickness of the layer.

Osborne, H. (Trans. A. I. E. E. 1910, vol. 29-2, p. 1553) gave revised form ulas for the design of graded cables. He also advanced the theory that solid heterogeneous dielectrics fail due to corona in the elements of lower specific capacity. This corona is assumed to be in the form of needle points.

Beaver, C. J. (*Jour. I. E. E.* 1914, vol. 53, p. 57) mentions disadvantages of graded insulations and claims that desired results could be better obtained by means of intersheaths, because (1) no chemical interactions, (2) easier to joint, (3) no electrical discontinuity, (4) could be tested layer by layer as manufactured, (5) much wider latitude in choice of potentials.

Clark, W. S. and Shanklin G. B. (Trans. A. I. E. E. 1919, vol. 38-1, p. 923) say that practically no advantage is gained by an attempt to grade with rubber, varnished cambric and impregnated paper because the maximum allowable working stresses in these materials are inversely as their specific capacities. They claim that it is better to have the insulation a homogeneous compact mass of impregnated paper.

VIII. Miscellaneous Data

Rheins, G. (*Comptes Rendus*, 1900, vol. 131, p. 505) says that the metal of cables penetrates the insulation and destroys its insulating properties. He said that after 20 years, gutta-percha insulation will show copper in its outer layers, whereas with impregnated paper only a few layers were penetrated in four years. (No other experimenters report this phenomenon).

O'Gorman, M. (*Jour. I. E. E.* 1901, vol. 30, p. 608) called attention to the effect of putting in series two elements of insulation having different specific capacities. He showed that the potential gradient is altered, the material of lower specific capacity carrying the greater part of the total potential drop across the two elements. (This fact seems to have been known to others at an earlier date.)

Newbury, F. J. (Cited by Perrine, Trans. A. I. E. E. 1902, vol. 19, p. 1067) said that in his experiments with fiber cables he could increase the dielectric strength of the cable up to a certain point, by increasing the thickness of insulation; beyond that point the cable seems to breakdown at almost the same potential, irrespective of increase in thickness.

Langsdorf, A. S. (*Elec. World* 1908, vol. 52, p. 942) reported tests on various insulating materials at frequencies from 30 to 110, that seemed to indicate that if the applied e. m. f. is above a certain critical value, breakdown occurs after a definite number of repetitions of the electrostatic stress.

Thornton, W. M. (*Phil. Mag.* 1910, vol. 19, p. 390) showed that the electrical movement in a dielectric, when isolated in the field, is entirely confined to the molecule and is therefore neither metallic nor electrolytic in type, but is a continued displacement of the atomic charges to a greater degree of separation.

Petersen, W. (*Archiv. fur Elektrotechnik* 1912, vol. 1, p. 28) showed that the refraction of lines of forces at the junction of two particles of different specific capacity in a dielectric may lead to an increase of dielectric stress.

Holttum, W. (Abstracted from a report to I. E. E. in *Electrician* 1913, vol. 71, p. 640) made tests on the relative dielectric strengths of ebonite for instantaneous and prolonged 50-cycle voltages and found that for stresses lasting a tenth of a second, the strength is only 25 per cent greater than for long continued stresses.

Lichtenstein, L. (*E. T. Z.* 1917, vol. 33, p. 1179) says that the progress in the use of thin walls of insulation for high voltages is not due to a lower standard of safety in working, but to improved chemical, physical and mechanical processes of manufacture. He says that probably at very high test pressures an excess of 25 or 50 per cent over the working pressure ought to suffice.

Butman, C. A. (*Elec. World* 1918, vol. 71, p. 812) showed that the specific capacity of a heterogeneous combination, such as of fullerboards soaked in oil, separated by three layers of paraffin, may be greater than that of either component alone. Thus, combination = 4.25, fullerboard = 3.32, paraffin = 3.69.

Fernie, F. (*Electrician* Oct. 10, 1919, p. 416) pointed out the superior dielectric strength of oil around small as compared with large conductors.

Zeleny, J. (*Phys. Review* 1920, vol. 16, p. 102) explained the added dielectric strength of an ionizable dielectric in contact with a small electrode as being due to the high potential gradient at the surface of the electrode as compared with that a short distance away, the velocity of the ions consequently dropping below the value necessary for ionization by collision, when they have travelled a short distance from the electrode.

Fernie, F. (*Beama*, Sept. 1921, p. 244) suggested that the stress which determines the failure of a cable is the minimum stress not the maximum.

Flight, W. S. (*Journal I. E. E.* 1922, vol. 60, p. 218) gives data on the effect of heat on the electric strength of paper, micarta, varnished cloth and other materials. He showed that the electric strength of varnished cloth is about 42 per cent less at 100 deg. cent. than at 30 deg. cent., that of oil saturated paper, about 27 per cent less.

Acknowledgment is made of the assistance given by the following Institute members who were so kind as to assist the subcommittee in the preparation of this summarized history: Messrs. R. W. Atkinson, F. W. Peek, C. E. Skinner, D. M. Simons and F. A. Westbrook. The Subcommittee on Wires and Cables appreciates the incompleteness of the summary, and has made but little effort to settle questions of priority in discovery. It is hoped that the discussion will correct whatever deficiencies may exist.

Dielectric Losses and Stresses in Relation to Cable Failures

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Review of the Subject.—*When transmission cables were first operated at potentials exceeding about 7500 volts, it was noted that cable failures occurred in service with loads materially below those which had theretofore been found to be permissible with low-voltage cables, and this reduction in carrying capacity increased with increase of the normal working potential. For example the author has previously reported that No. 0 A. W. G. four conductor cables operating on a four-wire three-phase system with a maximum normal potential of about 4000 volts between phases carry 200 amperes on each of three conductors without damage due to the overheating, whereas a 250,000-cir. mil cable operated at 20,000 volts was found to have excessive burn-outs if the load exceeded 175 amperes per conductor.*

For a number of years it has been recognized that this reduction in carrying capacity of high-voltage cables was due to the dielectric losses and a number of papers have been presented to the Institute on this subject. A temperature survey of the 20-kv. cable above mentioned showed that nearly all of the burn-outs occurred in a portion of the conduit near the substation, which conduit contained a large number of heavily loaded cables, and in which the temperature was 10 deg. to 15 deg. cent. higher than the rest of the conduit. This portion of the 20-kv. line was replaced over two years ago with cable having a low dielectric loss, since which time no further cable failures have occurred.

The method of analysis first suggested by Bang and Louis and later extended by Clark and Shanklin was applied to this particular case, and the carrying capacity for the cable as determined in this manner was found to agree closely with the results of experience. The method was therefore extended so as to determine the law connecting the size of conductor, the dielectric loss and the carrying capacity. Curves and charts are presented showing the carrying capacity of all sizes of three-conductor cables above 100,000 cir. mils and of the entire commerical range of dielectric losses. These results were then compared with the operating records of a transmission system having cables ranging in size from No. 00 A. W. G. to 500,000 cir. mils and with operating voltages of 9, 12, 20 and 22 kv. The results of this comparison appear to indicate that practically all failures on these transmission lines, which were not due to external damage to the lead sheath, were due to the cables being loaded beyond their safe carrying capacity, and that the dielectric losses had not been given proper consideration in determining the carrying capacity of these cables.

During the year 1921 the number of cable failures on the 20,000-volt lines was about one per hundred miles. This was about the same as the record on the 9000-volt cables, and this result leads to the conclusion that when the transmission cables are operated at safe loads, in the determination of which dielectric losses have been given proper consideration, the resulting failures are of the order of one per hundred miles per year. This result indicates that very few of the cable failures which have occurred in the past are due to dielectric stresses and that most of the failures occur due to the reduction in dielectric strength caused by the heating of the cables above their critical temperature.

Foreign cable manufacturers and operating engineers have apparently appreciated the reduction in carrying capacity due to dielectric losses as they ordinarily limit their maximum conductor temperature to a point well below the critical temperature as determined by these investigations. Their publications also appear to indicate that they fully appreciate that the quality of the insulation is of prime importance and that increased security cannot be obtained by increasing the thickness of insulation without improving the quality. The tests on cables made at the factory indicate that with the thicknesses of insulation that are commonly used in this country, and with the insulation of the first quality, the cable will pass the test required by the Standards of the A. I. E. E. with a wide margin of safety.

Dielectric strength tests made on foreign cables and reported in the technical press indicate that the dielectric strength is generally materially above the corresponding figures obtained from tests on cables made in this country by a number of leading manufacturers. Apparently some material reductions in the thicknesses of insulation now used in this country for the transmission voltages can be made if the insulation is of first quality and has a low dielectric loss.

CONTENTS

INTRODUCTORY

DURING the past few years a number of papers concerning dielectric losses of impregnated paper insulation has been presented to the Institute and has contributed interesting and valuable information to our knowledge of this subject. As this knowledge increased, it has been apparent to some engineers that many of our transmission cable burn-outs were due to the dielectric losses and the resultant heating and not primarily to the dielectric stresses. In the past, engineers in charge of the operation of transmission cables have repeatedly stated that transmission cables did not burn out from overload, and apparently based this statement on their experience with the carrying capacity of low-voltage cables. It now appears that these statements were in error, and that in making these statements, the engineers did not appreciate the extent to which the carrying capacity was limited by the dielectric losses. If the present symposium, of which this paper is a part, will do something toward clarifying our ideas on the relation of dielectric losses, dielectric stresses and temperature of the insulation to cable failures, it will have served a very useful purpose.

To be presented at the A. I. E. E. Annual Convention, Niagara Falls, Ontario, June 26-30, 1922.

Data on Cable Failures

In order to secure some data which might assist in reaching proper conclusions on this subject, the records of the transmission line of the Commonwealth Edison Company for the past eighteen years have been compiled and are shown in Figs. 1, 2 and 3. In preparing

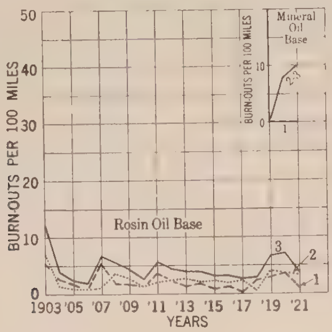

Fig. 1—Record of 9000-Volt Transmission Cable Failures
On system of Commonwealth Edison Company.
Curve 1—Internal troubles.
Curve 2—External damage.
Curve 3—Total.
Troubles due to lightning; failures on tests and joint troubles excluded.

these records, all failures caused by external injury to the lead sheath or by lightning, or failures on test, and all joint troubles have been eliminated so as to leave only failures of the cables which occurred in service. The amount of transmission line in service throughout this period is shown in Fig. 4.

Previous to 1919 all of the cables on this system had the paper insulation impregnated with a rosin oil compound. Beginning with that year, the cables have been purchased under specifications which included a dielectric loss guarantee, and in each succeeding year there has been some reduction in these guarantees. As a result, this record includes transmission cables ranging in size from No. 00 A. W. G. to 500,000 cir. mils and having dielectric losses ranging from about

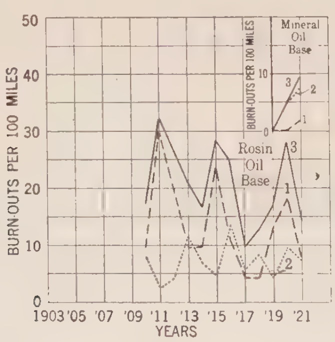

Fig. 2—Record of 12,000-Volt Transmission Cable Failures
Curves 1, 2 and 3, same designations as Fig. 1.

0.5 to 15 watts per foot or more when measured at 85 deg. cent. at their normal operating voltages of 9, 12, 20 and 22 kv. It would be confusing to show the dielectric loss curves in watts per foot for this large range of sizes, as the losses vary with the size of the conductor. It will be more illuminating to show the range of power factors of the dielectric loss for the various kinds of cable, and an assortment of such curves is shown in Figs. 5 and 6.

In order to analyze the operating results for the purpose of determining which, if any, of the cable failures have been due to dielectric losses, it is necessary to

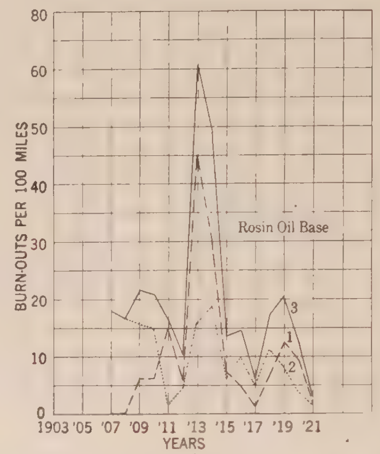

Fig. 3—Record of 20,000-Volt Transmission Cable Failures
Curves 1, 2 and 3, same designations as Fig. 1.

devise some method of rating the cables, that is, a method of determining their carrying capacity which will take into consideration the dielectric losses as well as the copper losses. Such a method was suggested by Bang and Louis in their Institute paper on Dielectric Losses, presented in June, 1917, and further developed by Clark and Shanklin in their paper on Single-Conductor High-Tension Cable, presented to the Institute in June, 1919. The application of the method may be best understood by its application to a specific example.

In March, 1917 there was placed in service a 250,000-cir. mil three-conductor 22,000-volt transmission line,

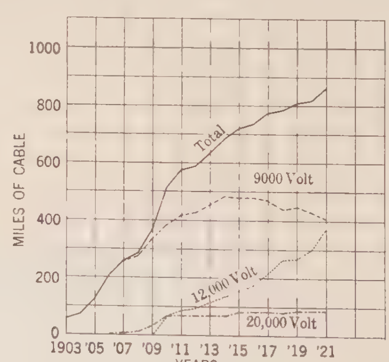

Fig. 4—Amount of Underground Transmission Cable in Service, Commonwealth Edison Company

No. 3801, from a suburban generating station into one of the outlying substations. The 4000 feet of this cable next adjacent to the substation was in a heavily loaded conduit, and repeated burn-outs occurred in this section. A temperature profile of this conduit taken by a recording thermometer in one of the vacant

ducts is shown in Fig. 7. A sample of this cable was tested for dielectric loss, and the results are shown in Fig. 8. In the hope of reducing the number of failures in this cable, the 4000 feet in the heavily loaded con-

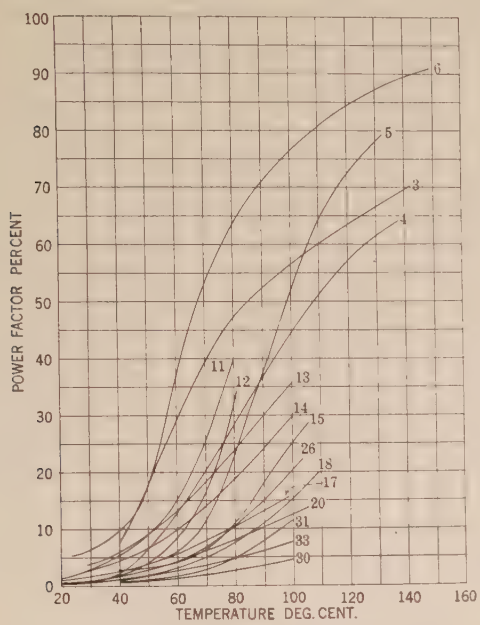

FIG. 5—DIELECTRIC LOSS CURVES OF 12,000-VOLT CABLES

The highest power factors are from cables impregnated with rosin oil compounds. The lowest losses are from cables impregnated with a mineral oil compound. The intermediate curves are from cables with various mixtures of the two compounds.

duit was replaced with cable having a low dielectric loss as shown in Fig. 8. In the same figure is also shown the Clark and Shanklin line for average duct radiation which was obtained as the average of a large number of observations, and shows for each tempera-

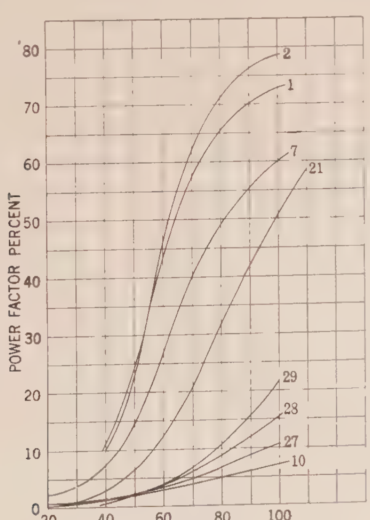

FIG. 6—DATA SIMILAR TO FIG. 5 FOR 20,000-VOLT CABLES

ture the number of watts that can be radiated from the cable in one duct. In order that the temperature of the cable may be constant, the losses in the cable must equal the amount of heat radiated. With a curve showing the variation of dielectric loss with temperature to start with, we can for any temperature subtract the dielectric losses from the total radiation and secure the copper losses. From the latter figure, the current in the cable can be readily calculated. The results of such calculations for the old and the new cable are shown by curves in Fig. 8.

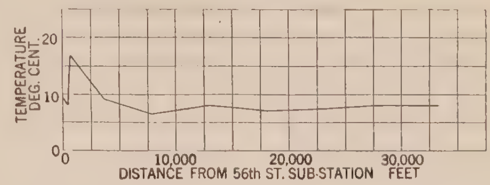

FIG. 7—TEMPERATURE PROFILE IN VACANT DUCTS ALONG LINE NO. 3801

Taken about April 1, 1922.

The temperature near the substation was lower at this time than at the time of the line failure described in the text due to several loaded cables having been removed from the conduit line, thus reducing the total losses in conduit about 15 or 20 per cent.

A chart from the recording ammeter on this line is shown in Fig. 9. This chart shows a normal load of about 150 amperes on the line up to about 5:20 p. m. at which time, owing to some trouble in other portions of the system, the load was increased to about 225 amperes for about an hour and three-quarters. As it was known that this line would not carry this load continuously, the load was reduced about 7:15 p. m. to what was considered a normal load for the line, and this load was carried until about 11 p. m., when a

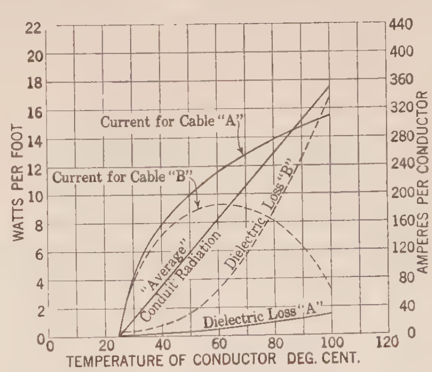

FIG. 8—DIELECTRIC LOSS CURVES OF OLD CABLE (A) AND NEW CABLE (B) ON LINE NO. 3801 AND CURVES OF CARRYING CAPACITY AS CALCULATED FROM CLARK AND SHANKLIN LINE FOR AVERAGE DUCT RADIATION

These cables were 250,000-cir. mil., three-conductor with 19/64-in. paper around each conductor and 7/64-in. outer belt, for a normal working voltage of 22 kv. Old cable had round conductors, new cable has sector-shaped conductors.

further reduction occurred. The line burned out the following morning about 3:30 a. m.

Referring now to Fig. 8, it will be noted that the current of 225 amperes was materially above the critical current for this line. This means that the losses in the cable were greater than the radiation, so that the temperature rapidly increased. A peak load of 175 amperes had previously been found possible

with this line if it did not continue very long and was sharply reduced thereafter. In this case, however the load of 175 amperes, which is about the critical load for this line, followed a peak load somewhat greater so that the temperature of the line having been materially increased by this heavy load, the total

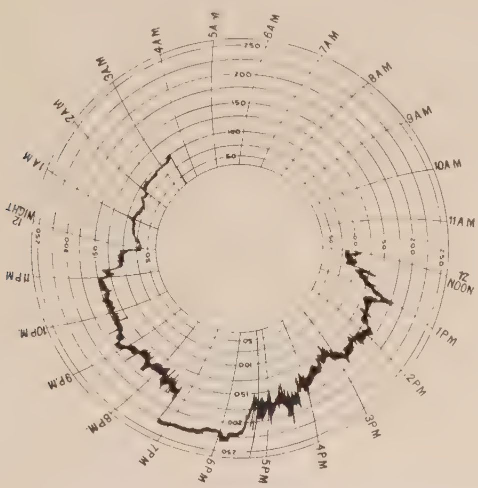

Fig. 9—Recording Ammeter Chart on Line No. 3801

Showing a load in excess of the critical current in the evening, followed by failure about 3:30 the following morning, October 28, 1919.

losses with 175 amperes were still above the radiation line, and the temperature continued to increase so that when the load was still further reduced to 100 amperes about midnight, the temperatures continued to increase until the line failed. These statements do not mean that the temperature of the cable throughout its entire length increased as above described, and

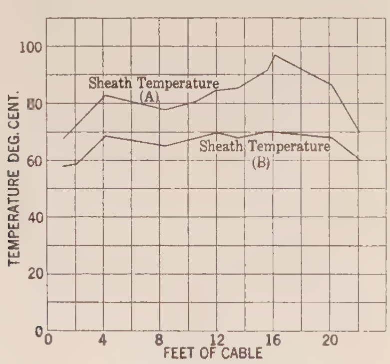

Fig. 10—Laboratory Heat Test on 250,000-Cir. Mil Three-Conductor Cable

With 6/32-in. insulation around each conductor and 4/32-in. outer belt paper insulation impregnated with rosin oilcompound. Reproduced from Report of Underground Systems Committee, National Electric Light Association, 1913.

A. Cable operated with 225 amperes at 12,000 volts.

B. 225 amperes, 0 volts. Temperatures taken by thermometers.

in fact it is very probable that the temperature did not increase above normal except for a very small portion of the cable where the dielectric losses were higher than in the adjacent portions. This is demonstrated by Fig. 10 which shows the results of a laboratory test made on a piece of 250,000-cir. mil, three-conductor cable and is from the N. E. L. A. Underground Systems Committee report for 1913. This cable was operated with 225 amperes on each conductor, and with 12,000 volts between conductors. It will be noted that the heating in the cable was far from uniform throughout its length and that at one point the temperature was about 18 deg. cent. above another point eight feet distant. The figure indicates that had the thermometer at this high point been a little further to the right, a still higher temperature would have been recorded.

Following the experience in this case, the practise was adopted of shifting the load within a few hours after a heavy peak load had been carried so that the line could be opened at both ends thus stopping the dielectric losses. The line then cooled rapidly so that it was at normal temperature before being placed in service for the day load the following morning. This method of operation was followed until the cable in

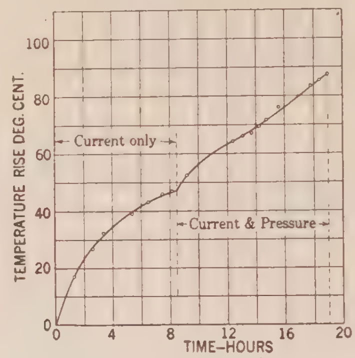

Fig. 11—Heat Run on No. 00 Three-Conductor Cable

With 9/32-in. insulation around each conductor and 6/32-in. outer belt paper insulation, impregnated with rosin oil compound.

the 4000 feet of hot conduit had been replaced by the cable with low dielectric loss, and as a result, no further burn-outs have occurred on this line.

It is quite possible however, that cable failures due to dielectric losses may not occur until several days after the line has carried a load in excess of the critical current. This may be illustrated by Fig. 11 which shows the increase in temperature in a cable which carried current only for about 9 hours and then current and potential for 10 additional hours. The upper part of this temperature curve indicates that had the test been continued a few hours longer, the curve would have become concave upward in which case the cable would have failed within a short time.

If a cable carries a maximum load that is less than the critical current each day on an ordinary load cycle with a daily load factor of about 50 per cent, then the cable will cool to about the same minimum temperature each night. If the cable carried for an hour or two a peak load, that exceeds the critical current, the minimum temperature at the time of minimum load

will be a little higher than the minimum which occurs in the ordinary cycle. Suppose, now, that the peak load exceeded the critical current for a sufficient time so that the minimum temperature following was, say,

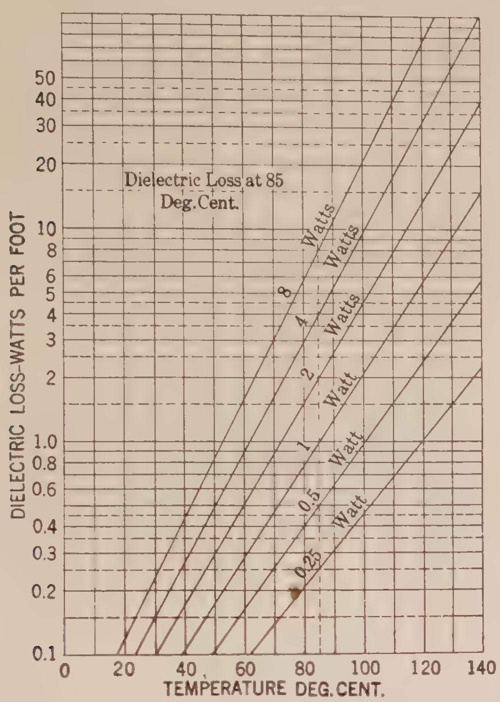

Fig. 12—Dielectric Loss Data Assumed for Purposes of Calculations

Based on a number of laboratory tests made for Commonwealth Edison Company.

In referring to these curves later, the lines will for convenience be designated by their loss at 85 deg. cent.

15 deg. higher than normal. This would mean that the cable would start on its ordinary load cycle 15 deg. warmer than usual, and its maximum temperature with its ordinary load cycle would probably exceed the

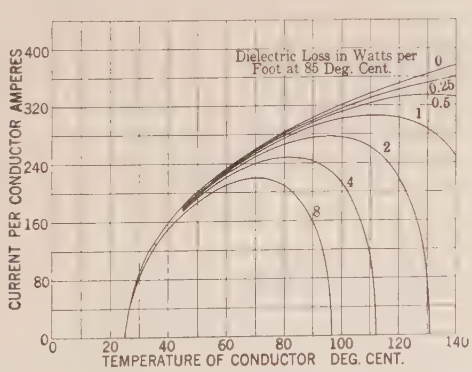

Fig. 13—Carrying Capacity of 250,000-Cir. Mil. Three-Conductor Cables

With dielectric losses as shown in Fig. 12 calculated from the Clark and Shanklin line for average duct radiation.

critical temperature on the following day. Under such circumstances, the maximum temperature would increase somewhat day after day, with the ordinary load cycle, and in a few days the increase would be sufficient so that the cable would not fall below the critical temperature even at the time of minimum load. Then a burn-out would follow in a comparatively few hours, as illustrated above on Line 3801. Many of the failures of cable due to dielectric losses have occurred in this manner several days after the unusual load or other abnormal temperature conditions which were the primary cause of the failure.

It is not necessary that the exact cycle above described be followed in order to produce a cable failure from dielectric loss, and a failure may result whenever the temperature of the cable is raised in any manner to a point above the critical temperature. The trouble may be due primarily not to the load on the cable which fails, but to heavy loads being carried on other cables in the same conduit so as to raise the ambient tem-

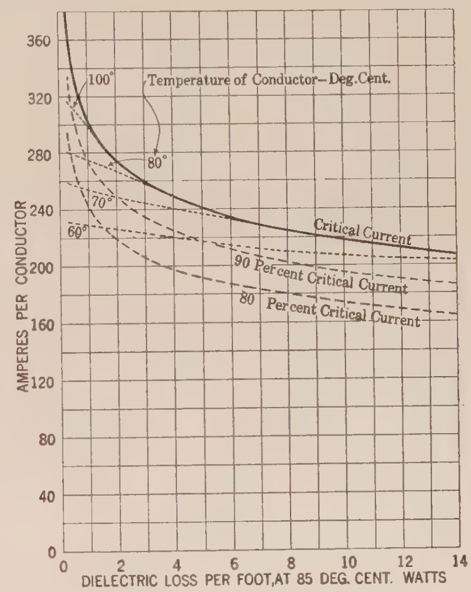

Fig. 14—Curve Showing the Effect of Dielectric Loss on the Critical Current of 250,000-Cir. Mil. Three-Conductor Cable

Plotted from curves in Fig. 13.

perature. External sources of heat will also produce the same result, such as steam being turned into a sewer which is adjacent to the conduit line. Most companies operating high-voltage transmission lines have had experience with cable failures due to such causes. One company reports that it had to move transmission lines out of conduits which were laid close to the curb wall because of a bake oven located under the sidewalk and next to the curb wall. Other companies have reported difficulties due to the radiation losses from underground steam mains 15 to 20 feet distant.

Extending This Method to Cover All Grades of Cable

By securing dielectric loss curves from cables covering a wide range of losses per foot, we can make similar calculations for a number of sizes and thus discover

the manner in which dielectric losses affect the carrying capacity.

Figs. 5 and 6 give the dielectric loss results from a large number of cables, and with these and other similar data we can assume a number of dielectric loss curves over the entire commercial range of dielectric losses. It is not possible to make these assumptions with minute accuracy because the dielectric loss curves of cable furnished by different manufacturers are of different shape. After trying a number of ways of plotting the curves, it was found that when they were plotted on semi-log paper, part of the curves would be convex upward, part straight lines, and part convex downward. Accordingly the assumptions were made as shown in Fig. 12 and these assumptions fairly represent the average of the dielectric loss curves from cables over a wide range of quality as obtained from six different cable manufacturers.

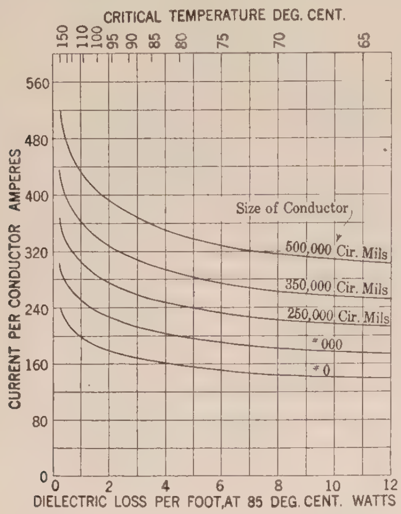

Fig. 15—Curves Showing for Several Sizes of Cable, the Variation of Critical Current and Critical Temperature with Dielectric Loss

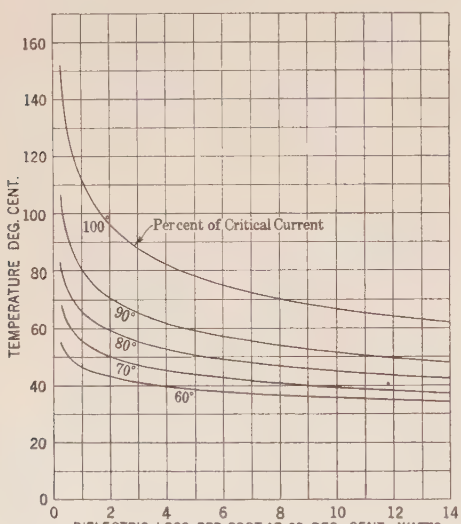

Fig. 16—Curves Showing Variation of Critical Temperatures with Dielectric Loss

For each of these assumed dielectric loss lines, calculations for 250,000-cir. mil, three-conductor cable were made as shown in Fig. 13. It will be noted in this figure that each of the curves of cable having the higher dielectric losses has a maximum point, called the critical current, which occurs at the critical temperature. It is, therefore, possible to plot this critical current against the dielectric loss as shown in Fig. 14. By adding the isothermal lines and the curves corresponding to 80 per cent and 90 per cent of the critical current, the data plotted in this way become a very convenient form for studying the performance of any particular size of cable.

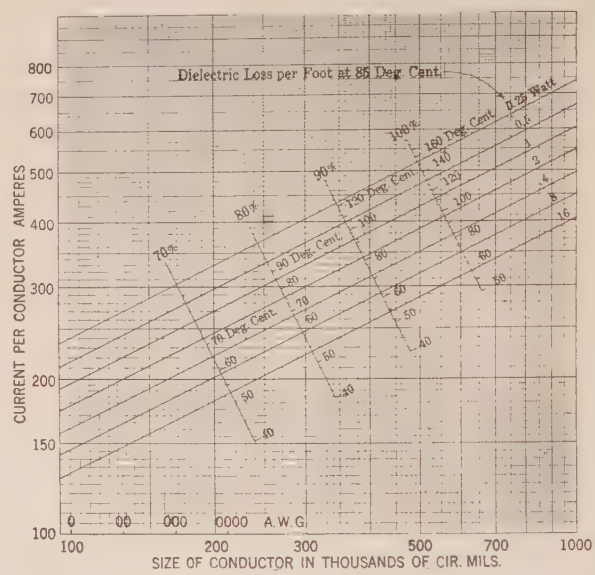

Fig. 17—Current-Carrying Capacity of Three-Conductor Lead-Covered Cables

With various dielectric losses and calculated from the Clark and Shanklin line for average duct radiation and from the dielectric loss lines shown in Fig. 12.

For a 250,000-cir. mil cable with four watts dielectric loss, the critical current is found to be 248 amperes. By following along the four-watt line to the 100 per cent scale, we find that the maximum copper temperature would be about 83 deg. cent. To find the temperature corresponding to 90 per cent of the critical current, multiply 248 amperes by 0.90, equals 223 amperes. Find this point on the 250,000-cir. mil line and then follow parallel to the diagonal lines to the 90 per cent temperature scale and get corresponding temperature of 62 deg. cent.

Similar calculations for a number of sizes of cable have been made, and their critical currents plotted against dielectric loss are shown in Fig. 15. In plotting these curves, it was noted that all sizes of cables having the same dielectric loss in watts per foot reach their critical current at the same temperature. It is therefore possible to add a temperature scale as shown in Fig. 15. From Fig. 13 and Fig. 15 it will be noted that a cable without dielectric loss has no critical current, and also that a cable with a low dielectric loss reaches its critical current at a temperature above the maximum permissible temperature for impregnated paper insulation.

In Fig. 16 is shown the curve of variation of the critical temperature with the dielectric loss. It would obviously be quite impossible to operate cables at their critical temperatures as determined by a dielectric loss test on a sample of cable, as such a test gives the average loss per foot for the entire sample and does not show the maximum dielectric loss at any point on the cable. Accordingly additional curves are included in Fig. 16 which show the temperatures that would be reached with several percentages of the critical current. From these curves it will be noted that a material reduction in the maximum temperature of the insulation can be made by a moderate reduction in the current below the critical current.

If the curves shown in Fig. 15 are transferred to logarithmic coordinate paper as shown in Fig. 17, it is found that the curves become straight lines and this permits using the calculations for all sizes of cable.

Fig. 17 shows the rating of all sizes of cables and in a full commercial range of dielectric losses as calculated by this method. By comparing this rating with the operating records of the system under discussion, and using as the ambient temperature the temperature obtained by a recording thermometer in an idle duct and about twenty feet from the manhole, we find that first, the transmission cables have in the past been frequently operated at or above their critical currents, and second, if the loads on the transmission cables are limited to about 90 per cent of the critical currents during the cooler months of the year and to about 80 per cent in the summertime, transmission line failures due to the dielectric losses will be practically eliminated.

Analysis of the Cable Failure Records

Referring now to the cable failure records of the 9000-volt cables, as shown in Fig. 1, this curve shows occasional peaks, and although the dielectric losses at 9000 volts are comparatively low, we know that some of these failures followed serious overloads. Some of these cases of trouble have occurred on one of three lines to a substation when one line was out of service on account of construction work in the substation, and some accident placed a second line out of service, thus putting the whole load on one line. In Fig. 3 showing the cable failure records of the 20,000-volt cables, there are several very pronounced peaks. It is now quite thoroughly understood that these peaks were due to the overloading of the cables beyond their critical current. The very pronounced peak in 1913 and 1914 followed the addition of a 24-hour load to the load previously carried on one group of lines which was reduced by the installation of an additional line in 1915. The pronounced peak in 1919 was due largely to the troubles on Line 3801 above mentioned. In 1921 however, after the low-loss cable had been substituted for the high-dielectric-loss cable in the hot conduit, and after a portion of the load on certain other lines had been transferred to the 12,000-volt, 60-cycle system, thus bringing the load on all 20,000-volt cables below their critical current, it is to be noted that the cable troubles dropped to about one per hundred miles per year or about the same as for the 9000-volt cables. This result indicates that practically all of our previous cable troubles on the 20,000-volt lines were dielectric loss failures and that when the load on these cables are kept within the limits at which the dielectric loss failures occur, then the remaining failures, that is, the failures due to dielectric stresses are quite insignificant.

The causes for the peaks in the 12,000-volt cable failures are more complicated. When the 12,000-volt system of tranmission to substations for alternating-current distribution was first installed to replace the motor-generators previously used for changing the frequency from 25 to 60 cycles, some of the old 9000-volt cables were transferred to 12,000-volt service. In addition, other cables were installed having the same insulation as the 9000-volt lines. Quite a few of these cable troubles were due to paper insulation being torn by sharp bends in manholes, and a larger number perhaps was due to the attempt to carry on these lines the same loads as had been previously carried on the 9000-volt lines, that is, due to the failure to make a proper allowance for the reduction in carrying capacity caused by the increase in dielectric losses at the higher voltage.

The two latter peaks were due in large part to the failures of cable forming tie line between large generating stations. On account of the necessity of cleaning and overhauling the turbo-generators in these stations, it is necessary to shut each generator down for a period of several weeks during the light-load period, and as a result of the load on these tie-lines is frequently at a maximum during this generator cleaning period in the summer-time. A number of these 12,000-volt cable failures also occurred in a conduit near the Northwest Station, where for a distance of about one block, two heavily loaded conduits were only a few feet apart, thus affording insufficient opportunity for the radiation of the heat. This trouble was stopped temporarily by cooling the conduit line with a stream of water applied intermittently. Later the 12,000-volt rosin-oil-impregnated cables were replaced with other cables having low dielectric losses.

Particular attention has to be paid to this question of conduit temperature, due to heavily loaded cables in the vicinity of stations and substations. Fig. 18 shows the temperature profiles of two conduit lines between the Fisk Street Station and the Calumet Station, in which there are several pronounced peaks along the route in the vicinity of substations. There is also a pronounced peak near the Fisk Street Station due to temporary storage of coal on the ground above the conduit line.

Another feature of interest in Fig. 2 is the record of cable failures due to external causes. These cables,

as above mentioned, have the same insulation thickness as the 9000-volt cables. On a large system it would, at first thought, be reasonable to suppose that the percentage of failures due to external causes would be the same for all voltages of cable. Quite a few instances have occurred, however, where 9000-volt cables had their lead sheath damaged and no failure occurred,

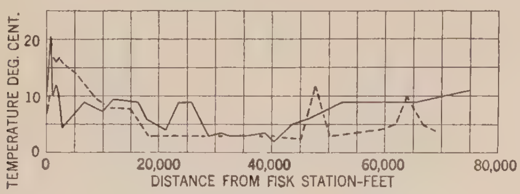

Fig. 18—Temperature Profiles Along Two Conduit Routes Between the Fisk Street Station and the Calumet Station

whereas under the same circumstances failures have occurred in the 12,000-volt cables. Several of these 12,000-volt failures assigned to external damage have occurred in cables which, upon being withdrawn for repairs after failure occurred, showed marks on the lead sheaths, indicating damage at the time of installation. A number of cases of damage to the lead sheath of 9000-volt cables have been found when the cables were being withdrawn for reinstallation at another location, and experience appears to indicate that had these cables been operated at 12,000 instead of 9000 volts, cable failures would have resulted. In one case, a 9000-volt cable, upon being withdrawn, was found to have the lead sheath burned off for a maximum length of two feet and a maximum width of about two inches, and the burn extended entirely through the outer belt insulation. This cable was installed in single-duct vitrified tile conduit and the damage had been caused by the failure of another cable in an adjacent duct about one year previously. The cable which was withdrawn had been in service throughout this period in the damaged condition and without developing any trouble at this location, although the cable was only six inches above the permanent ground water level.

These several experiences appear to indicate that the 9000-volt cables have such an excess of insulation for the working voltage, that the increased dielectric stress due to these injuries to the lead sheath is not sufficient to cause a cable failure, although failures of 12,000-volt cable would generally occur under the same conditions.

Another contributing cause for the increased number of external damage failures of the 12,000-volt cables is that these lines have been installed more recently than the 9000-volt lines, and are therefore installed in ducts above the 9000-volt cables. Damages due to digging in the street would, therefore, be more likely to affect the 12,000-volt cables.

Results of Tests on Cables at the Factories

During the past three years the cables for addition to this transmission system have been purchased under specifications practically identical with those included in the report of the Underground Systems Committee of the N. E. L. A. for the year 1920, and the cables have been carefully tested at the factory in order to insure that they complied with the specifications in all respects. In addition, laboratory tests were made on impregnated paper from the cables to determine its quality.

Fig. 19 shows the results of a series of such tests that is quite representative and typical. In the folding endurance test the number of double folds of different samples varied from 45 to 13,000, while the other tests showed a much smaller variation.

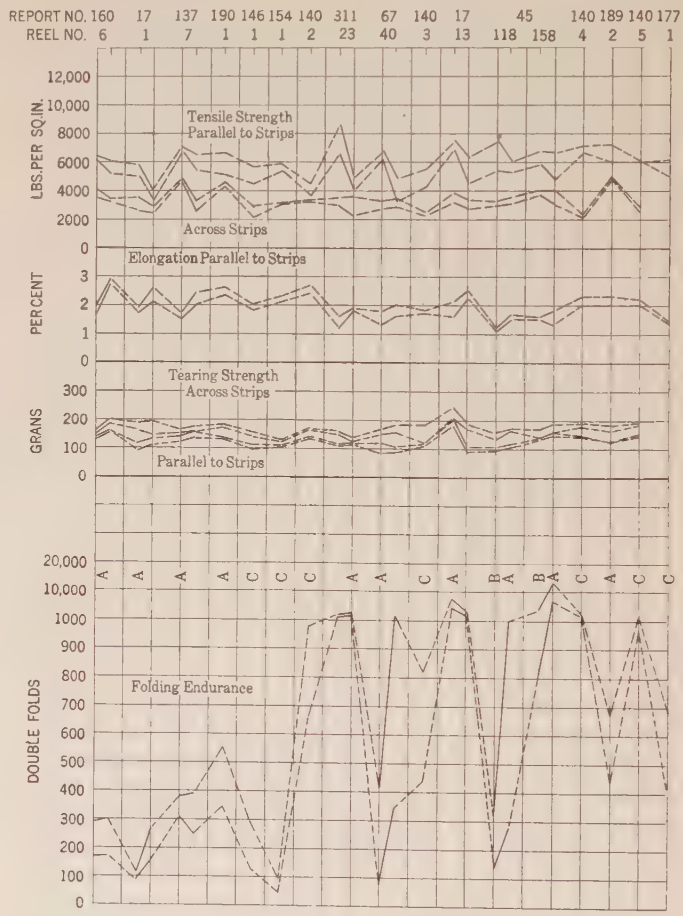

Fig. 19—Typical Tests on Physical Properties on Impregnated Paper Insulation Showing Variation in Quality of Paper

The two lines given for each series of tests represent the average and minimum values of results of tests on several samples of paper from each piece of cable. *A* denotes no tearing of paper in bending test in accordance with N. E. L. A. cable specifications; *B* denotes slight tearing, and *C* very bad tearing.

The tests made on these cables at the factory also showed a very large variation in the dielectric strength of the samples. In general, however, the cables passed the tests required by the Standards of the A. I. E. E. with a rather wide margin. As a result, the thickness

of insulation during this period has been gradually reduced. For low-voltage cables the reduction in thickness of insulation has been about 50 per cent and for the high-voltage cables about 25 per cent to 35 per cent. Before making the last reduction, sample reels of cables with thin insulation were secured from several manufacturers and submitted to all the regular and special tests called for by the Standards of the A. I. E. E. and the N. E. L. A. cable specifications. The thicknesses as finally adopted are practically the same as the recommendations by the British Engineering Standards Association for voltages below 6000 and above this are practically the same as the thicknesses being used by some of the larger English companies. However, one of the latter companies has recently, on the basis of its own experience and on the advice of its consulting engineers, made a further reduction of 25 per cent in the thickness of insulation of cable for 20,000 volts normal operating pressure, the insulation being 300 mils between conductors and 210 mils to ground. The usual British practise calls for a maximum copper temperature of about 50 deg. cent. for transmission cables. Correspondence with English consulting engineers and cable manufacturers shows that their high-voltage cables have about the same dielectric losses as those furnished by the leading manufacturers in this country, that is, if measured at 85 deg. cent. the dielectric losses on their 20-kv. cables would be of the order of one watt per foot. By referring to Fig. 14, it will be noted that for a dielectric loss of one watt per foot and a copper temperature of 50 deg. there is a rather wide margin between the operating current and the critical current which might result in cable failures due to dielectric losses. Apparently therefore our British friends are of the opinion that as long as they continue to operate their cables under conditions which eliminate burn-outs caused by dielectric loss heating, then they can secure satisfactory operation with an insulation thickness less than two-thirds of what is considered necessary in this country.

Relation Between Insulation Thickness and Dielectric Stresses

As a result of a thorough and persistent search, the author has reached the conclusion that there is in use in this country no scientific basis for determining the thickness of impregnated paper insulation on high-voltage cables. In the earlier days, when impregnated paper cables were first made, the manufacturers appear to have adopted the thicknesses of insulation previously used on cables with rubber insulation. No bending tests were made on these earlier cables, and the cables were installed with the same sharp bends that had previously been found permissible with rubber-insulated lead-covered cables. Our later knowledge indicates that many of these early failures must have been due to the tearing of the paper insulation caused by the bending during installation. Many of the older foremen and splicers who were raised on rubber insulated cables were quite firmly of the idea that it did not matter how sharp a bend or kink was made in the cable during its installation so long as these sharp bends and kinks were removed before leaving the cable in its final position.

As troubles from these earlier paper insulated cables occurred, the manufacturers and users, instead of making a determined effort to locate and remove the cause of trouble, adopted the simpler course of increasing the thickness of insulation, and until the last few years it does not seem to have occurred to anyone that they might have more insulation on their cables than necessary.

Several manufacturers in this country are making impregnated paper tubing consisting of paper impregnated with some insulating compound and then heat-

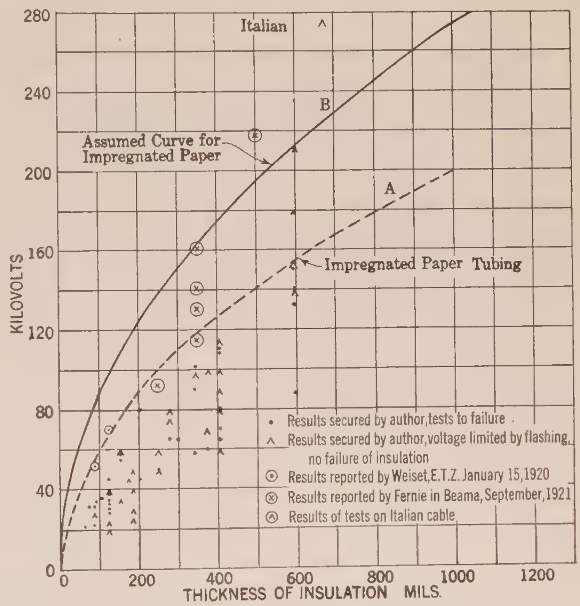

Fig. 20—Dielectric Strength Tests on Impregnated Paper Insulation

A. Curve of dielectric strength guaranteed by one maker of impregnated paper tubing, in which the dielectric strength is proportional to the square root of the thickness.

B. Curve similar to *A* assumed by author from results of one test on 33-kv. cable.

treated so that the resulting material is very similar in its make-up to impregnated paper insulation used in lead-covered cables. One of these manufacturers in its circulars states that a quarter inch thickness of this material will stand a 100-kv. dielectric strength test, and further, that the dielectric strength varies with the square root of the thickness. From these data, curve *A* in Fig. 20 has been drawn.

The author in criticising the manufacturer of some cable with 600 mils insulation between conductors because the manufacturer had been satisfied with a dielectric strength test that was limited by cable bell trouble, attempted to make a dielectric strength test on a 15-foot sample, carrying the pressure to 212 kv.

between conductors. In this case also the pressure was limited by cable bell trouble and there was no failure of the cable within the lead sheath. Assuming that the dielectric strength of impregnated paper insulation also varies with the square root of the thickness, and using this particular point as our starting point, then we get the curve shown by B in Fig. 20. On the same sheet are also shown two points given by Weiset in the *E. T. Z.* for January 15, 1920, also six points given by Fernie in *Beama* for September, 1921, and also one figure giving results from an Italian cable, the latter data being obtained from private sources. On the same sheet are also shown the results of a large number of dielectric strength tests on various thicknesses of insulation made for the author on cables purchased in the last three years. For those thicknesses of insulation where a large number of tests are available, these results show a ratio of maximum to minimum greater than 2 to 1.

In testing the cables purchased under specifications, it was noted that at first the paper was not applied smoothly, that is, without wrinkles, and that difficulty was encountered by some manufacturers in applying the insulation so that it would pass the bending test. As these difficulties were brought to the attention of the manufacturers, it was found that it was not a serious matter to eliminate the difficulties by having the paper tape of the proper thickness and width and applied with a suitable tension and the right amount of lap. As these difficulties were eliminated, the dielectric strength test of the cables increased, so that finally for such thicknesses of insulation as are common in this country for 25 kv. it was found that the voltage required to cause failure of the cable under the dielectric strength test was quite beyond the testing facilities available in practically all of the cable factories. It would thus appear that by suitable care and perhaps some additional inspection in the factories, the American cable manufacturers should be able to make their cable of more uniform quality so that it would give results more nearly corresponding to the available data on foreign cables.

The American Engineering Standards Committee in gathering foreign specifications and standards for the use of its recently appointed Sectional Committee on Insulated Wires and Cables received an interesting communication from a Dutch Standards Committee which includes the following statement:

> The Association of Managers of Electric Central Stations have made an extensive study on high-tension cables, the results of which have been published. * * * * The most interesting result disclosed by this study is that, contrary to most opinions of today, it is not the thickness of insulation which gives the best guarantee for the reliability of the cable, but that the influence of the quality of the insulation material is very much greater.

How long will it be before American manufacturers will adopt the Dutch plan of increasing the reliability of their cables, not by increasing the thickness of insulation but by improving the quality?

The author recently had an interesting discussion with one of the technical executives of one of the larger manufacturing companies. This engineer had made some suggestions that certain changes should be made in the details of the manufacture of a certain line of electrical apparatus so as to improve the quality of the product. These changes were at first violently opposed by the superintendent of this factory, but after a thorough investigation the changes were put into effect. Then it was discovered that, in spite of the increased inspection and greater care in manufacture which resulted in a marked improvement in the quality, the improved manufacturing methods had brought about a reduction of about 5 per cent in the cost of the finished product. Is it not possible that a similar result might be secured in the manufacture of impregnated paper-insulated lead-covered cables?

Conclusions

1. After excluding the cable failures caused by lightning, external damage to the lead sheath and joint troubles, the remaining transmission cable failures on the system have been largely dielectric loss failures; that is, the cables have been loaded beyond their critical current as determined by their dielectric losses and cumulative heating, which followed, caused the cable failures.

2. The only cable failures that can be definitely ascribed to the dielectric stresses are a few that have been caused primarily by the tearing of the insulation due to sharp bends during installation.

3. Temperature readings in conduits are just as important as ammeter readings in the stations in determining the safe loads for transmission lines.

4. Some scheme of testing should be devised so that by means of some simple measurements it may be possible to determine the radiation constants of different portions of conduit lines in service and establish current ratings of transmission cables so as to eliminate the burn-outs due to overloads.

5. The thicknesses of insulation considered necessary in this country for transmission cables have been determined largely by experience with the cables in which the insulation was impregnated with a rosin oil compound and had high dielectric loss. If the Rules in the Standards of the A. I. E. E. are a sufficient criterion of the quality of the cable, then the thicknesses of insulation ordinarily used for transmission cables in this country can be very materially reduced, as cables with the present thicknesses of insulation with material and workmanship of the first quality, will pass the tests prescribed by the Standards of the A. I. E. E. with a wide margin frequently exceeding 100 per cent.

6. High-voltage cables having a low dielectric loss can be safely operated at temperatures materially higher than are possible with high-loss cables, due to the increase of the critical temperature with the reduction in dielectric losses.

7. The permissible operating temperature of high-dielectric-loss cables is limited by the critical temperature above which cumulative heating occurs. In low-loss cables the temperature is limited, as in low-voltage cables, by the temperature which the paper insulation will withstand without deterioration.

8. Until the proper method of calculating the limiting stresses of high-voltage cables and the limiting values for these stresses is determined, it will not be possible to design cables with the thickness of insulation properly proportioned to the working voltage.

9. If the dielectric losses of transmission cables are properly taken into consideration in fixing their carrying capacity, then for the thicknesses of insulation that are commonly used in this country, the percentage of burn-outs of the high-voltage cables should be no larger than for the lower transmission voltages and should not exceed one or two per hundred miles per year.

10. When the carrying capacity of a transmission cable with high dielectric loss is limited by the temperature of a short portion of the conduit in which it is installed, it may be found profitable to replace this portion of the cable with low-loss cable, and thus secure an increased carrying capacity for the entire line.

On the Minimum Stress Theory of Cable Breakdowns

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Review of the Subject.—*For the rational and economical design of electric cables, it is important to know the relation be-between the dimensions of the cable and its breakdown strength. Many different theories have been proposed in the past, such as the maximum stress theory, the average stress theory, Russell's theory, and Osborne's theory, all of them conflicting. Recently a new theory has been proposed by Fernie that the minimum stress, namely that at the sheath of a cable is the limit. It is the purpose of this paper to discuss Fernie's theory and data, inasmuch as it is so diametrically opposed to some of the earlier theories. It seems quite plausible that insulating materials have a specific breakdown stress. Fernie having discovered, as he states, that the minimum stresses were constant in his tests, feels forced to abandon this idea and attempts to explain his results in terms of a limiting value of stress at the sheath, namely the minimum value. An analysis of his test results, however, does not seem to justify him inasmuch as, although his minimum stresses were much more constant than the maximum stresses, they were by no means constant, and in fact, it could be claimed with almost equal justice that his test results vindicated the average stress theory.*

Since, however, Fernie's experimental minimum stresses present a certain degree of constancy, this phenomenon (which remains to be proved) is investigated further. It is shown that if it be assumed (1) that the inner layers of insulation may be overstressed without complete rupture of the cable due to the stable equilibrium of the remainder of the insulation, and (2) that insulating materials have a critical breakdown gradient, a direct result of these two hypotheses is that the minimum stress at breakdown is a constant, though it is not in itself the criterion.

It may be concluded therefore, that Fernie's experimental data are not sufficient to justify his claim that the minimum stress is a constant, and that if later tests should prove the constancy of minimum stress, this phenomenon could be explained otherwise than by assuming that the minimum stress itself is the limit.

CONTENTS

A KNOWLEDGE of the relation between the breakdown strength of cables and the size of conductor and insulation thickness is very important, if cables are to be rationally and economically designed. For instance, in a series of single-conductor cables all of the same insulation thickness, varying from small conductors to large conductors, will all these cables break down at the same voltage, or will those with small conductors break down at the highest voltage, or the lowest voltage? This fundamental question has not been adequately and convincingly answered even for the simplest case of all, the case of single-conductor cables. It is probable that it will never be possible to determine exactly the breakdown strength of a particular cable, due to the inherent lack of uniformity of insulating materials, but if a general law could be discovered, obtained by averaging the results of a great many samples, it would at least be possible to design cables with the same factor of safety. Any such law would also of course have to take into consideration the effect of time. A great many theories have been proposed, some of them quite conflicting, but there is a surprising lack of published experimental data on the subject. It has been claimed that the maximum stress in the insulation is the limit, that the average stress is the limit, as well as other intermediate theories. There has recently been proposed a radically different explanation. This theory is one offered by Fernie, who claims that the *minimum* stress or the stress at the sheath is the limit in the breakdown strength of single conductor cables[1]. Inasmuch as his theory is based on a greater amount of data than hitherto published and in view of the considerable

To be presented at the A. I. E. E. Annual Convention, Niagara Falls, Ontario, June 26-30, 1922.

1. Fernie, "Insulating Materials," *Beama*, page 244, 1920.

interest evinced in this country in his conclusion, a discussion of his data and theory finds a proper place in this symposium. It is the purpose of the present article to discuss Fernie's data and to suggest a different explanation of his experimental results, and show that it is quite possible that the minimum stress may be constant and yet not in itself be the limit in the breakdown strength of cables.

For our purpose it will be assumed that insulating materials have a specific breakdown strength, which could be determined by puncture tests between parallel plate electrodes, inasmuch as in this case the stresses would be uniform throughout the insulation. Due to limits of space, no further discussion will be made of the many qualifications which should be made of this statement.

If an insulating material is contained between concentric cylindrical electrodes, such as the case of single-conductor cables, the stress, or gradient (or voltage per unit thickness) is by no means constant, but is a maximum at the conductor surface and a minimum at the sheath, and these two may be calculated by the following formulas:

$$G_{max} = \frac{E}{r \log_e R/r} \qquad (1)$$

$$G_{min} = \frac{E}{R \log_e R/r} \qquad (2)$$

where E is the voltage between the conductor and the sheath, R is the radius over the insulation, and r is the radius of the conductor.

One of the first theories of the breakdown strength of cables was that since every insulating material has a critical breakdown strength, which we may call G_0, as determined by the breakdown of layers of insulation between parallel plate electrodes, a single-conductor cable will break down as soon as this critical stress is exceeded in the insulation, which means that breakdown should occur when the maximum stress at the surface of the conductor is equal to the critical stress G_0. According to this maximum stress theory, if a series of cables of different dimensions and the same insulating material should be broken down, the calculated maximum stresses of all the cables at the breakdown voltage should be a constant and equal to the critical stress G_0. This would mean that for cables of a given insulation thickness, the larger the conductor, the higher would be the breakdown voltage.

The maximum stress theory of the breakdown strength of cable ignores one fundamental and well-known characteristic of the stresses in single-conductor cables, which may be briefly stated as follows. *For cables of a given outside diameter and given impressed voltage, the minimum value of the maximum stress at the surface of the conductor will exist when R/r equals ϵ, the base of the natural system of logarithms, or 2.72.* This characteristic may have an important bearing on the theory of the breakdown strength of cables. If a cable is of such proportions that R/r is greater than 2.72 and a high voltage is applied such that the inner layers of insulation tend to break down, this would result in virtually increasing the size of conductor, which would *diminish* the maximum stress in the insulation. The stresses in the remainder of the insulation would all be increased, but the maximum stress would be less than the maximum existing before the inner layers punctured, ane would therefore be less than the critical value. On the other hand, if R/r is equal to or less than 2.72, any puncturing of the inner layers of insulation will tend to *increase* the maximum stress. Cables may therefore be divided into two classes, which we shall call Class 1 in which R/r is greater than 2.72, and Class 2 in which R/r is equal to or less than 2.72. Russell[2] and Osborne[3] have developed different theories on the breakdown strength of cables, which take this feature into consideration, and which are well worth further study. Osborne takes issue with Russell's theory, but neither one publishes very much experimental data to prove his point. According to neither of these theories would the maximum stress or the minimum stress be constant at breakdown as calculated from the cable dimensions and the breakdown voltage.

Fernie's Theory

Fernie, as stated before, has advanced a new theory. He performed a series of breakdown tests on cables of different sizes of conductor and insulation thicknesses, and has published his results, these results being probably the most complete experimental data on this subject on record. He states that it seems a very plausible theory that an insulating material should have a critical breakdown strength, and that therefore the cable should break down as soon as this value is exceeded in the cable insulation. If the maximum stress theory is true, the calulated maximum stresses at breakdown for the cables of a given insulating material should be constant. His results show that the maximum stresses are far from constant, varying in fact by over 200 per cent in one series, but he makes the remarkable statement that his minimum stresses were very closely constant. Based on his experimental data, he proposes that the minimum stress is itself the limit, and advances an interesting explanation of why this should be so, which explanation does not take the specific breakdown gradient into consideration.

Fernie's Data

The comment has been made that Fernie's data are quite extensive, and it may be added that they are considerably more consistent than most of the data which have been published on this subject. It is by no means, however, intended to imply that they are

2. "Dielectric Strength of Insulating Materials and the Grading of Cables," A. Russell, *Journal I. E. E.*, Vol. 40, page 6, 1907.
3. "Potential Stresses in Dielectrics," H. S. Osborne, Transaction, A. I. E. E., 1910, page 1553.

sufficiently consistent to form in itself the basis of a new theory or to disprove some of the older theories. It is desired to discuss this phase of the matter briefly, and Fernie's experimental data are therefore shown in the following two tables. Table I refers to the data of his Table II, and Table II corresponds to the data of his Table III. R is the radius of the insulation, r is the conductor radius, and t is the insulation thickness.

TABLE I.

R	r	t	R/r	$\log_{10} R/r$	Fernie's Break-down Voltage in kv.	Maximum Stress G_{max}	Minimum Stress G_{min}	Average Stress G_{av}
mm.	mm.	mm.				kv/cm.	kv/cm.	kv/cm.
11.32	2.43	8.89	4.65	.6672	160.0	428	92.0	180
17.97	5.27	12.70	3.41	.5327	217.0	335	98.3	171
12.59	3.69	8.89	3.40	.5318	130.0	288	84.3	146
14.16	5.27	8.89	2.69	.4292	134.0	257	95.6	151
16.26	7.37	8.89	2.21	.3437	140.0	240	108.7	158
11.62	5.27	6.35	2.21	.3434	91.5	219	99.5	144
17.06	8.17	8.89	2.09	.3198	114.0	189	90.6	128
					Averages	280	95.6	154
					Deviations	+53%	+13.7	+17
						−32%	−11.7	−17
					Average Deviation	23.1	5.9	8.7

TABLE II.

7	2	5	3.50	.5441	54.25	216	61.8	109
9	3	6	3.00	.4771	69.0	209	69.7	115
11	4	7	2.75	.4393	65.3	161	58.6	93
13	5	8	2.60	.4150	83.9	175	67.5	105
16	6	10	2.67	.4257	94.2	160	60.1	94
					Averages	184	63.5	103
					Deviations	+17	+9.8	+11.6
						−13	−7.7	−9.7
					Average Deviation	12.3	6.4	7.6

Certain types of experiment lead to quite definite results which can be repeated at will. Tests on the breakdown strength of insulating materials are of a very different kind, and very great discrepancies usually occur between tests on supposedly similar samples, or even on different samples of the same piece of insulation. It is therefore necessary in breakdown tests to perform an enormous number of tests in order to average out the irregularities. Fernie's experimental data are based on the average of a great many tests, but even this does not mean that the number was sufficient to establish a law. Probably the main cause of the difficulty in breakdown tests is the inherent lack of uniformity of insulating materials. Due to the essential difficulty of the problem, any set of experimental data must be examined very critically and consideration must be given not only to whether or not the data would tend to disprove one theory and prove another, but also to see if there are not other theories which might also apply with about the same amount of deviation from the observed results. It will be seen in Tables I and II that though Fernie's calculated minimum stresses present a certain constancy, they are by no means rigidly constant. Fernie makes no mention of either Russell's or Osborne's theories, nor of the average stress theory, and apparently had in mind only the maximum stress theory. The departures from constancy of his calculated maximum stresses are so much greater than those of his minimum stresses that he apparently felt justified in calling the latter constant. If those were the only alternatives, his results would probably be sufficient to establish his claim. In fact, it may be stated that his results give fairly strong evidence to disprove the maximum stress theory. The question, however, still remains as to whether or not his results are definite enough to establish a constant minimum stress theory as opposed to some of the other theories. In Tables I and II, are shown the calculated maximum, minimum (with some minor errors in his calculations corrected), and average stresses at the moment of breakdown, and also the maximum plus and minus, and average deviations from the average. It can be seen immediately that the deviations from constancy of his minimum stresses are only slightly less than those of the average stresses, and that in Table II, even the maximum stresses are not much less constant than the minimum stresses. It is believed therefore that Fernie's claim for constancy of minimum stress at breakdown is not justified by his own data, and, to epitomize, it could be claimed with almost equal justice that Fernie's data prove the constant average stress theory and also Osborne's theory. If considerable emphasis is placed upon the points obtained from the cables with small sizes of conductor given in Table I, Fernie's data give fairly strong evidence against the maximum stress theory, and would indicate that Russell's theory is not adequate, though the evidence is less pronounced in the latter case.

Even though Fernie's test results do not seem to be consistent enough to definitely claim that the minimum stress is constant and that the other theories are wrong, still it must be admitted that the deviations of minimum stress are somewhat smaller than the other deviations, and it is therefore worth while to consider his results further and see what conclusions could be drawn if a series of tests should definitely prove the minimum stress to be constant. The cables which would show the greatest difference in breakdown strength according to the different theories are those for the larger and smaller values of the ratio R/r. Fernie's entire range for this ratio is only from about 2.1 to 4.7. It seems unfortunate, therefore, that he did not use greater extremes in the dimensions of his cables in his tests, in spite of certain difficulties, since cables with large values of the ratio would so clearly differentiate between certain of the theories, and cables with small values of the ratio are more in accord with everyday practise.

Overstressed Insulation

The maximum stress theory assumes that the cable will puncture as soon as the critical stress is exceeded in any part of the insulation. Russell's theory assumes that no part of the insulation can sustain more than the critical stress, and that as soon as this value is exceeded, the insulation will break down and become

equivalent to a conductor; whether or not the entire cable will breakdown depends on the dimensions of the cable. The other theories of the breakdown strength of cables assume the possibility in some form or other of overstressed insulation. The constant average stress theory does so implicitly. Osborne's theory is based upon the conception that the critical stress may be surpassed in the insulation, but that this will lead to breakdown in certain weak points resulting in minute needle-like punctures extending outward from the conductor, which thereby relieves the stress in the remainder of this region of the insulation throughout which the stress will be constant and equal to the critical value.

The possibility of the existence of overstressed insulation is not a new thought. For instance we might quote Whitehead[4] as follows:

> There is no difficulty in the idea of a strain of dielectric material beyond the electrical elastic limit with no resulting structural breakdown and resulting conductivity. In a single-conductor cable, we may think of a string of molecules stretched radially along a line of electric force. When the interior portion of the insulation is overstressed, but the insulation as a whole unbroken, we may think of the component charges of a molecule in the stressed region as drawn apart, and a tendency on the part of opposite charges of two adjacent molecules to combine. If this tendency could take place along the whole line of force there would be combination throughout and resulting discharge. The phenomenon would then be similar to conduction in a metal. In the case as supposed, however, the outer portions of the insulation are not overstressed, consequently proceeding outward from the conductor along the line of force there comes a region where there is a molecule which is not overstressed, which therefore successfully resists the tendency of one of its charges to pass to the adjacent overstressed molecule. This restraining influence is therefore propagated backward toward the center and serves to keep the overstressed portion from breaking down entirely. In this way the region of safe stress may be said to aid that in which this stress is exceeded.

According to Whitehead's conception a certain critical value of stress is required to draw apart the component charges of a molcule. It seems reasonable to assume therefore, that this critical value of stress will be all that would be required in the inner layers in order to hold the charges in this physical condition. This would mean that the stress in the overstressed region of the insulation would be a constant and equal to the critical stress, and that the overstressed region of insulation would not maintain its proportional share of the voltage, but would consume only a sufficient amount of the total voltage to hold the entire overstressed region at the critical value of stress. This would lead to a theory of the breakdown strength of cables mathematically equivalent to Osborne's theory though physically different. It is interesting to note that there is no critical point, or critical radius such as occurs in Russell's theory. That is, if a certain amount of the inner layers of insulation which would tend to be overstressed are held at constant value of stress equal to the critical value, any tendency to puncture the layer of insulation immediately adjacent to the outer layer of overstressed insulation would result in diminishing the stress in the succeeding layers to a value below the critical value. In other words, the equilibrium is stable, and there is no tendency for complete breakdown of the cable according to this theory until the voltage is raised to such a point that *all* the insulation is subjected to the constant stress equal to the critical value. According to this theory, then, if a series of cables is broken down, the *average stress* in the insulation as calculated from the cable dimensions would be a constant equal to the critical breakdown strength of the insulation. This discussion, therefore, is merely an interpretation of the average stress theory, and it might be repeated that Fernie's data could with almost equal justice be claimed to prove either the constant minimum stress theory or the constant average stress theory. This conception of the conditions in the insulation does not however lead to a constant minimum stress at breakdown, which must therefore be sought on other hypotheses.

4. Whitehead, J. B., Discussion, TRANSACTIONS A. I. E. E., 1910, page 1582.

PROPOSED EXPLANATION OF THE MINIMUM STRESS THEORY

A given set of experimental data may often be explained by entirely different physical theories. It is hard to believe that the critical breakdown strength of a cable as determined by parallel plates is not in some way the limiting feature, and Fernie's explanation does not seem to be very convincing. It is desired to show here, that, if it is a fact that the minimum stress at breakdown is a constant, this may be explained rationally in terms of the critical breakdown strength of the insulation combined with the conception of overstressed insulation, as well as by Fernie's theory, based on the "skin resistance" hypothesis, though the latter may of course have to be considered also.

To do this, it it will be assumed first that overstressed insulation may exist if the *remainder* of the insulation is in stable equilibrium, and secondly, that the overstressed insulation can support its proportional share of the voltage; in other words, that the distribution of potential throughout the cable will not be affected by the fact that certain inner layers are stressed above the critical value. The case of a cable of Class 1 (R/r greater than 2.72) will be considered. Let us imagine that the voltage on the cable is raised until the critical gradient is reached across the layer of insulation next to the conductor surface. If this layer should break down, the result would be a virtual increase in the size of conductor diameter, which would mean that the stress on the next layer of insulation, though increased above its previous value, would still be less than the critical value. The equilibrium of the cable as a whole may therefore be considered stable, and according to this theory, it is assumed that the breakdown does *not* take place in the inner layer due

to the stable equilibrium of the whole cable. This is the distinction between this theory and Russell's theory. Russell assumes that actual breakdown and carbonization of overstressed layers take place. Here it is assumed that no action takes place but that the layers are overstressed due to the equilibrium of the whole system. Let us assume that the voltage is raised still higher. The inner layers of insulation will be stressed above the critical value, the maximum of course being at the conductor surface, and the critical stress will exist at a certain distance, x, from the center of the conductor. Having assumed the possibility of overstressed insulation, our attention must be directed upon the equilibrium of the remainder of the insulation, in other words between the region of radius x, where the critical stress G_0 exists, and the lead sheath. If R/x is greater than 2.72, any tendency for the critical gradient to puncture the layer at x would result in a stress upon the next layer which would be less than the critical gradient, and, as before, the equilibrium will be stable. On the other hand, if R/x is equal to or greater than 2.72, puncturing of the layer at which the critical gradient G_0 exists, would result in a stress upon the next layer higher than the critical value and we may consider the equilibrium as unstable. There is therefore apparently a critical point in the insulation, whose radius we shall call r' such that r' is equal to $R/2.72$. According to this theory, therefore, for cables of Class 1, as the voltage is raised continuously, the critical stress will first appear at the conductor surface and will then travel outward toward the sheath, all layers within this region being overstressed, the equilibrium of the cable as a whole being stable until the critical gradient reaches the raduis r', at which point it is assumed that breakdown will take place.

For cables of Class 2, in which R/r is equal to or less than 2.72, r' has no significance, and the cable would be in unstable equilibrium as soon as the critical gradient reaches the conductor surface. It would be expected, therefore, that breakdown would take place as soon as the critical gradient reaches the conductor surface, or in other words, the maximum stress theory would be applied to cables of Class 2, exactly as Russell did for cables of this class.

The results of this theory may now be examined mathematically. Let E' be the voltage between r' and R at the moment of breakdown. By formula (1) we may immediately express E' as follows:

$$E' = G_0\, r' \log_e R/r' \tag{3}$$

and remembering that the natural logarithm of 2.72 is equal to unity and that r' equals $R/2.72$, we may state

$$E' = 0.368\, G_0\, R \tag{4}$$

We may now solve for E, namely the actual breakdown voltage of the cable, inasmuch as the ratio of E to E' will be in inverse proportion to the relative capacities of the two sections. Therefore

$$E = \frac{\log R/r}{\log R/r'} \times E' = 0.368\, G_0\, R \log R/r \tag{5}$$

The above equation gives the expression for the breakdown voltage of a cable in terms of critical stress and the dimensions of the cable according to the present suggested explanation.

The maximum stress at the moment of breakdown may now be obtained by substituting this value of E in equation (1) and we find that at the moment of breakdown

$$G_{max} = 0.368\, G_0 \times R/r \tag{6}$$

The minimum stress at the moment of breakdown may also be obtained by substituting the value of E in equation (2) and we find that

$$G_{min} = 0.368\, G_0, \textit{ a constant} \tag{7}$$

It will therefore be seen that a direct result of this theory is that for cables in which R/r is greater than 2.72, the minimum stress at breakdown will be a constant, as calculated from the actual cable dimensions and the breakdown voltage, and that this theory, based on the rational conception of a critical stress, will adequately explain Fernie's claim that the minimum stress is constant at breakdown.

It is desired to point out that for the case of cables of Class 1 there is a distinct difference between this suggested theory and Fernie's theory, in spite of the fact that according to both, the minimum stress will be constant. According to this theory, the cable punctures when the critical stress reaches the region whose radius is r', and a direct incidental result of this is that the minimum stress is constant. The critical stress G_0 at r' is in itself the limit, and not the minimum stress at the sheath. While these two theories are the same for cables of uniform dielectrics, they would lead to entirely different results in cables where different layers of insulation have different permittivities, such as in the case of graded cables. Only experimentation can determine which of these theories, if either, is correct. One test performed by Fernie throws some light on this point, inasmuch as he broke down two samples of cable, one uniform and one graded, and the results would tend to confirm his theory rather than the present one, and this test must therefore be taken into consideration. On the other hand, there is no indication that he broke down more than one sample of each type, which in itself would greatly discount the results of this one test.

While the theory outlined above explains the constancy of minimum stress for cables of Class 1 in terms of the critical gradient, it appears to be a rather difficult conception in one point at least, namely in the stability of the equilibrium of cables of Class 1 for values of the voltage intermediate between that given by equation (5) and the breakdown voltage according to Russell's theory. The present conception assumes the possibility of overstressed insulation and in determining the stability of the system places attention upon the

understressed outer portions of the insulation, ignoring the inner, overstressed section. If investigation should be made as to what would happen to the cable as a whole, if the overstressed layers should give way, which seems a perfectly reasonable method of approach, it will be found that if the impressed voltage is higher than the breakdown voltage according to Russell's theory, and the overstressed layers should puncture, the stress at r' will be greater than the critical value, and the whole system would be in unstable equilibrium. If the applied voltage is less than Russell's breakdown voltage, the equilibrium will still be stable, and in fact, this method of approach would lead directly to Russell's theory, and would not lead to a constant minimum stress at breakdown as calculated from the cable dimensions. This would mean that there would be no distinction between Class 1 and Class 2 cables for a voltage higher than Russell's breakdown voltage, which leads to a difficulty, inasmuch as Fernie's data for the small sizes of conductor as shown in Table I give fairly strong evidence that the breakdown of these cables is higher than would be obtained according to Russell's theory. To explain this, it might be assumed that overstressed insulation (bearing its full share of the voltage) is possible and that breakdown will not take place until the critical stress reaches the sheath. This conception would lead to a constant minimum stress at breakdown for all classes of cable, the minimum stress being equal to the critical value. The difficulty is that conditions in Class 2 cables seem so essentially unstable as soon as the critical stress exists in the insulation that it is a little difficult to conceive of breakdown not taking place until the critical stress reaches the sheath. Also, this theory, as stated above, would mean that the minimum stress is equal to the critical stress, and Fernie's values of minimum stress seem too low for the critical stress of impregnated paper insulation. It does not seem necessary to adopt either of these theories, Fernie's theory, or possibly an entirely different theory, until definite experimental proof is obtained that the minimum stress at breakdown is constant.

Effect of Time

Up to the present, no mention has been made of the effect of time on breakdown voltage. This is a matter of the greatest importance, and it is believed that whatever law may be determined for the instantaneous breakdown strength of cables, the law would be quite different for cables in which the voltage is raised very slowly, for cables under long time test, or for cables in service. For instance, the present theory which involves the conception of overstressed insulation could not possibly hold in a cable of high dielectric loss under long time test, inasmuch as the heating of the overstressed layers would greatly change conditions, and would undoubtedly lead to breakdown in some cases from other causes. Quite aside, however, from the matter of the general heating of the cables due to dielectric losses, it is conceivable, and indeed probable, that there is a gradual deterioration of insulation which is overstressed, so that the limitation of working voltage of a single-conductor cable may well be the stress at or near the conductor surface, whereas the limitation of the voltage which may be sustained for short-time tests may be dependent upon some other function, such as the average stress, or even the minimum stress as suggested by Fernie.

Conclusions

It may be concluded that Fernie's data are not sufficient in themselves to justify his claim that the minimum stress is a constant at breakdown. The deviations of the minimum stresses from constancy are practically no greater than the deviations of average stress. There is, however, an indication that for the conditions of the tests and primarily their duration, the maximum stress theory is incorrect, though the data are inadequate to form the basis of a definite conclusion.

It may also be concluded that if a set of experiments should definitely indicate the constancy of minimum stress, even this would not mean that the minimum stress, or the stress at the sheath, is in itself the limit. The constancy of minimum stress may be explained in terms of the critical breakdown gradient of the insulation, together with the conception of overstressed insulation, and undoubtedly there are other methods of explanation.

The great present need in this problem seems to be experimental data. No attempt is made herein to go beyond experimental data which have already been published. The theory outlined herein is intended merely to show that Fernie's claim that the minimum stress is a constant is susceptible of another explanation, and no claim is of course made that the present theory is correct, because an essential of the theory is the constancy of the minimum stress for cables of Class 1, and this is not proved by the data published.

The forward-looking policy of the French railroads in electrifying their main lines is evidenced by the recent definitive action of the Paris-Orleans Railway, one of the six great systems of France. As a part of the program for electrification with the 1500-volt direct-current system, this railroad which operates over 5000 miles of route has placed a contract for 80 freight locomotives and 80 heavy high-speed passenger motor cars. The larger part of the order will be manufactured in France, but considerable material of American manufacture, it is understood, will also be required.

The engines will be used on an extension of the original electrification made a quarter of a century ago by the French Thomson-Houston Company with General Electric apparatus. The first section of the new 1500-volt section will cover 125 miles of dense main-line traffic between Paris and Vierzon.

Effects of the Composite Structure of Impregnated Paper Insulation on its Electric Properties

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The effect of composite structure upon the electric properties of dielectrics has been observed and theorized upon by various people, as mentioned in the Introduction. The present paper attempts to show a quantitative expression of power-factor and dielectric loss in terms of the resistivities and specific capacities of the elements of the insulation. It also shows the electrical function of the paper in impregnated paper insulation, and cites experiments which indicate that the electric failure of such insulation is due to ionic motion in the oil; the obvious deduction being that the voltage rating of cables should depend upon the degree to which ionic motion in the oil can be restrained.

CABLE dielectrics are composed of mixtures of various substances in which organic substances play the most important role.

Impregnated paper insulation consists principally of fibers of cellulose, surrounded by and filled with mineral oil. Rubber insulation consists of vulcanized rubber, hydrocarbons and various mineral substances. Varnished cambric insulation consists of cellulose fibers, air, oxidized oils and hydrocarbons. All of these components differ from one another in resistivity, specific capacity, and thermal characteristics and their juxtaposition leads to effects which influence the voltage at which they lose their insulating qualities.

Dielectric Loss

It is noted in the Committee's introduction that various physicists have explained residual charge and

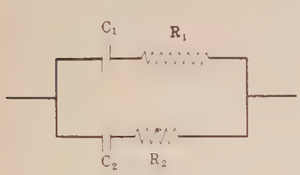

Fig. 1

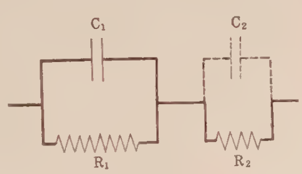

Fig. 2

associated effects on the basis of heterogeneity of the dielectric and that Fleming and Dyke suggested that a heterogeneous dielectric might be represented by a pair of condensers in parallel, each condenser having a resistance in series with it as shown in Fig. 1. Wagner gave a quantitative exposition of the effect of heterogeneity upon residual charge and hinted that a similar method might be applied to the study of dielectric losses.

Addenbrooke showed that Fleming's combination of parallel condensers leads to unsatisfactory conclusions. Following the logical development of Fleming's and Wagner's conceptions, the authors have tried the combination of condensers and resistances shown in Fig. 2.

If a leaky condenser, represented diagrammatically by C_1 and R_1 in Fig. 2 be placed in series with a resistance R_2 and an alternating potential impressed across the combination, the reactive as well as the active component of the current will, of course, be carried through the resistance R_2 and will cause a loss of energy therein. If the resistance R_2 be shunted by a condenser of capacity C_2 some of the current will be carried by that capacity (without energy loss) thereby reducing the energy loss in the resistance R_2. If the capacity C_2 be increased, a condition will be attained where the entire reactive component will be carried by the two condensers in series, and the active component by the resistances in series, no current then circulating across the connection. When the capacities and resistances are so proportioned, the energy loss in the combination will be a minimum for a given total resistance.

Some years ago, the authors noted a correspondence between residual charges and dielectric loss, those insulations having high residual charge invariably showing high dielectric loss. This afforded a confirmation of Wagner's suggestion and a theoretical analysis was made of the energy losses in a circuit consisting of two leaky condensers in series, for which see Appendix I.

The net result of this analysis was the following equation for the power factor of impregnated paper insulation. (See Appendix II)

$$\cos\theta = \frac{\dfrac{\rho_1}{a_1+1} + \dfrac{\rho_2}{a_2+1}}{\sqrt{\dfrac{\rho_1^2}{a_1+1} + \dfrac{\rho_2^2}{a_2+1} + \dfrac{2\,\rho_1\,\rho_2\,[1+\sqrt{a_1\,a_2}]}{(a_1+1)\,(a_2+1)}}}$$

Where ρ_1 = resistivity of impregnating compound ohm - cm.
ρ_2 = resistivity of cellulose fibres, ohm - cm.
K_1 = specific capacity of impregnating compound
K_2 = specific capacity of cellulose fibers
f = frequency of alternating e. m. f.

$$a_1 = \left(\frac{\rho_1\,K_1\,f}{18\times 10^{11}}\right)^2$$

$$a_2 = \left(\frac{\rho_2\,K_2\,f}{18\times 10^{11}}\right)^2$$

The specific capacity of petrolatum, the type of mineral oil generally used for this purpose, is about

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two and that of cellulose fibers about four, values which do not vary greatly with the grade or temperature. The resistivities of both substances vary enormously with the temperature, and in the case of petrolatum, to a considerable extent with the chemical composition. It is therefore of interest to see how the power factor varies with the resistivity of the petrolatum at a given temperature, say 85 deg. cent. assuming the other quantities to remain constant.

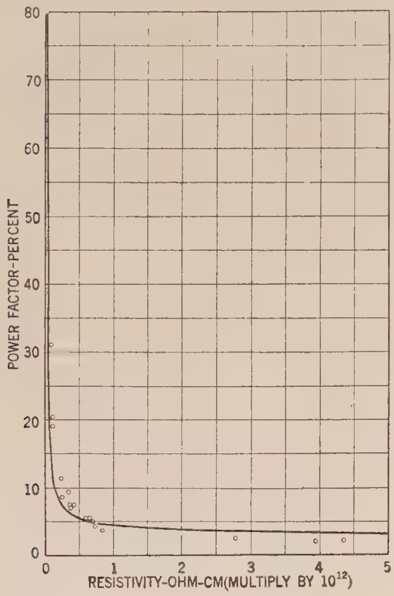

Fig. 3

Experimental data, represented by small circles, compared with theoretical curve.

Unfortunately a practical difficulty stood in the way —the determination of the resistivity of cellulose. The resistivity desired is not that of paper, nor even of paper fibers, but of the walls of the fibers. The fibers are about 7 mm. long and 0.02 mm. in diameter and they have a variable wall thickness of the order of 0.005 mm. It seemed almost impossible to make resistivity measurements upon such small specimens. Another difficulty was that the resistivity derived from measurement depends upon the time of electrification. As the research was primarily industrial, rather than purely scientific, it was decided to assume the equation to be correct, deduce the resistivity of the cellulose therefrom by tests based upon known values of specific capacity and oil resistivity. This was done for a one-minute electrification and at a temperature of 85 deg. cent. The resistivity of the cellulose at that temperature was found to be 0.07×10^{12} ohm-cm., a value consistent with tests by A. Campbell on other forms of cellulose.

Assuming this value, the power factor of the insulation was calculated for other oil resistivities. A graph of this relation is shown in Fig. 3.

Experiments were made both upon flat samples and upon cables and the results are shown by the circle-enclosed dots in Fig. 3. It will be observed that the experiments confirm the theory fairly well over a range of power factors from 2 per cent to 80 per cent.

This theory is not offered as a complete explanation of dielectric loss, but merely as an approximate working theory to guide designers. The phenomenon is undoubtedly far too complicated to be covered by any simple formula and a great deal of research work will be required before a complete explanation can be offered.

According to the above theory, the power factor should be inversely as the frequency when ρ_1 and ρ_2 are so great as to make the leakage current negligible. It should be independent of the frequency when ρ_1 and ρ_2 are so small as to virtually short circuit the capacities. For intermediate values, the power factor should decrease with increasing frequency according to the equation. The authors have not yet had an opportunity to make experimental checks of the effect of frequency.

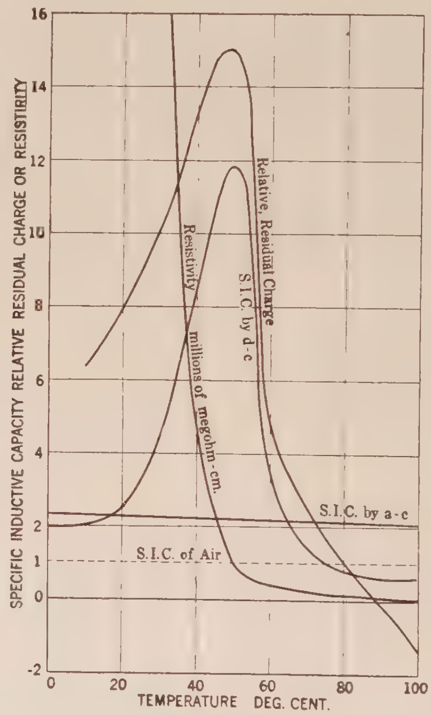

Fig. 4

The same general reasoning might be applied, although with greater difficulties, to the evaluation of dielectric loss in rubber compounds and varnished cambric insulation. It must be remembered, however, in applying the theory, it is assumed that no moisture is present, as a very small proportion will have a greater effect than even a fairly large reduction in the resistivity of one of the essential constituents. It is greatly to the credit of those concerned with manufacture that it is possible to obtain cables in which the moisture content is entirely negligible.

As dielectric loss in a well dried, well impregnated paper cable depends principally upon the conductivity of the oil, the loss must occur principally in the oil.

The work of Pungs, cited in the introduction to this symposium tends to show that conduction in oil is due to ionic travel rather than to mere ionic displacement. According to this theory, which is confirmed by tests cited below, a high-loss cable, *i. e.* one in which the "a-c. conductivity" is high, is liable to have the ions in its oil set into unduly rapid motion, a condition favorable to electric failure.

Evidences of Free Ions

The test of any theory lies in its ability to explain phenomena. The test is especially satisfactory if a simple theory is found to explain a complicated series of phenomena. Regarded in this light, the theory that petrolatum normally contains free ions of both polarities is very satisfactory. The theory was effectively used by L. Malclès to explain the phenomena which occur when a petrolatum condenser is charged and discharged, using an electrometer to measure the charges. He showed that the behavior of such a condenser depends upon the viscosity of the petrolatum which, in turn, depends upon its temperature, and he explained this on the basis that the mobility of the ions is an inverse function of the viscosity.

Tests of capacity were made both by the d-c. and the a-c. methods, readings being taken over a range of temperature from 0 deg. to 100 deg. cent. and on a great number of specimens. The d-c. tests were made with a ballistic galvanometer, the petrolatum being in a cell, details of which are given in Appendix III. An example of the results is shown in Fig. 4 which gives the characteristics of a rather poor grade of petrolatum chosen for purposes of illustration because of the exaggerated degree to which it shows the phenomena under consideration.

Consider first the curve of apparent specific capacity, as measured by direct current.

When the condenser is charged, the negative ions are drawn toward the positive electrode and the positive ions, toward the negative electrode. When the condenser is discharged the ions diffuse from the electrodes, and redistribute themselves at random throughout the petrolatum at a rate depending on its fluidity. The current resulting from this ionic diffusion may or may not add itself to the true discharge current for the following reason: An appreciable interval of time elapses, in testing, between the end of the charge and the beginning of the discharge through the galvanometer circuit and the diffusion of the ions may occur in this interval. In this case the diffusion current would not be observable and the apparent capacity would equal the true capacity. This was found to occur at about 75 deg. cent.

With lower temperatures, the petrolatum being more viscous, the diffusion of ions is slower, until at a certain temperature it should last through the interval between the end of the charge and the beginning of the discharge. At lower temperatures, it should last longer, but should be weaker. Hence, at a certain temperature, the diffusion of ions should occur at such a speed as to make the apparent capacity a maximum. This temperature was found to be in the vicinity of the melting point, 50 deg. cent. In the case recorded in Fig. 4, the apparent capacity as measured with direct current, is about seven times the capacity as measured with alternating current. At yet lower temperatures the ionic diffusion is so slow, due to the viscosity of the petrolatum, that it should have little effect upon the apparent capacity. This condition was found at temperatures below 20 deg. cent.

If the petrolatum is sufficiently viscous the ionic diffusion which follows a discharge may continue long after the completion of the capacity test, and, if the condenser plates are kept insulated from one another, this redistribution of ions will result in residual charges on the plates. The residual charge one minute after the initial discharge was measured and the value at 80 deg. cent. arbitrarily taken as unity in order to show the relative values at different temperatures. These values are plotted in Fig. 4, and show that the residual charge reaches a maximum at a temperature slightly below the melting point. This would be expected from the theory of ionic diffusion because the residual charge should be most evident when the petrolatum is soft enough to permit diffusion but not so fluid as to allow this diffusion to be complete before the minute interval has elapsed.

Thus far we have considered only ions of molecular dimensions. Electrons will behave differently by virtue of their ability to travel through conductors. Electrons will be attracted to the positive electrode, but unlike the ions of molecular dimensions will not remain in the petrolatum. They will be drawn into the electrode and charging circuit and a corresponding number will appear on the negative electrode.

If the charging potential be removed, the electrons will diffuse through the petrolatum. If the electrodes be connected through a galvanometer, the moving electrons will set the electrons in the circuit moving in opposite direction to the discharge current, thereby reducing the apparent capacity and on later discharge, making the residual charge appear to be negative. These effects predominate only at such temperatures as correspond with very low viscosity, when the diffusion of molecular ions is so rapid as to produce no appreciable effect upon capacity measurements. In Fig. 4 this begins to occur at about 90 deg. cent.

The ionization theory of the residual charge of petrolatum does not explain the entire residual charge in a cable, this being due largely to the juxtaposition of the particles of oil and cellulose at whose surfaces charges are induced by virtue of their different specific capacities.

Function of Paper in Impregnated Paper Cables

An experiment was made to ascertain the effect upon the dielectric strength of petrolatum, of interposing various numbers of sheets of paper between

testing electrodes. The experiment was made in an oil-testing cup having flat surfaced cylindrical electrodes ½ in. in diameter. The results are plotted as Curve *A* in Fig. 5, which shows clearly that in spite of the fact that after inserting the paper the oil was more highly stressed, due to the introduction of a dielectric of higher specific capacity, its dielectric strength increased as it was divided into thinner laminas by the introduction of more sheets of paper.

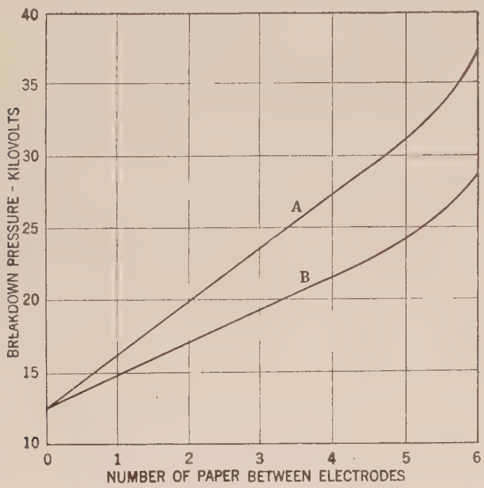

Fig. 5

If the paper be severely creased, and the crease viewed under a microscope, the line of the crease will be revealed as a hedge of fibres sticking out of the surface. In a cable, such projecting fibres will not act as barriers to ions trying to get through the paper, as they are loose and lie along, not across, the path of such ions. Hence we should expect badly creased paper, or paper with loose fibers, to be a less effective baffle to the ions and therefore to be less effective than smooth, tight paper in raising the dielectric strength of oil. An experiment similar to the last described was made with the only difference that badly creased paper was used. The results are shown by Curve *B* Fig. 5. It will be noted that both curves show a decided upward tendency, and further experiments, with different oils and papers have shown that this upward tendency continues as the number of papers increases, but experimental difficulties with the high voltages required to breakdown a wide gap, prevented obtaining a smooth curve for a much larger number of papers. Isolated experiments, however, indicate that the ratio of the breakdown voltages for uncreased and creased papers, keeps on increasing as the number of papers is increased, until it is at least two.

An interesting experiment was made with a radio frequency generator which showed in a very simple way the effect of serious creases upon the dielectric strength of impregnated paper. A plate of metal was connected to one pole of the generator and a movable wire connected to the other pole. The latter was held above the plate at such a distance that when about 17,000 volts were applied between wire and plate luminous white streamers extended between them. A sheet of oil-impregnated paper was then laid on the metal plate, with the result that the white streamers stopped immediately. When the wire was brought a little nearer the plate, faint purple streamers spread out from the wire, and flattened out over the paper. The crease in the paper was then brought within three cm. (horizontally) of the wire, the wire being one cm. above the paper. White streamers then spread from the wire to the plate through the crease as shown in Fig. 6.

Another sheet of impregnated paper with many creases was substituted for the first sheet and the wire moved slowly at right angles to the creases. Streamers jumped from crease to crease, never puncturing the uncreased paper.

A similar experiment made with unimpregnated paper, showed that the streamers were not attracted by the creases and proved that the harmful effect of creases is due to their effect upon the insulating properties of the oil rather than upon that of the paper itself.

The conclusion to be drawn from these experiments is that the electrical breakdown of impregnated paper is due to ionic motion in the oil, which is obstructed by the paper fibers.

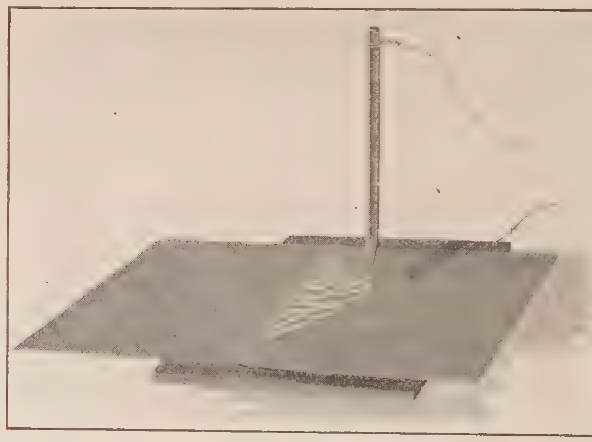

Fig. 6

Conclusions

Three sets of experiments have been cited and a theoretical explanation of each set has been given.

The first experiments indicate that when the power factor of impregnated paper insulation has been lowered as far as possible by the removal of air and moisture, there remains an element of power factor which depends upon the resistivity of the oil. This element is far too great to be explained on the basis of leakage current but may be explained as due to current which passes inductively through the capacity of the cellulose fibers and conductively through the oil.

The second experiments indicate that the oil used in impregnated paper insulation normally contains free ions in considerable quantities.

The third experiments indicate that the failure of impregnated paper insulation may be due to the establishment of streams of ions in the oil.

It would be logical to deduce from these considerations that in designing and using high-voltage cables particular care should be taken to impose every possible restraint upon ionic motion in the oil.

The practical means of accomplishing this are as follows, it being assumed that manufacturing processes will eliminate all air, vapor, and moisture:

1st. Use paper of a quality and thickness that will have the maximum baffling effect.

2nd. Apply the paper so that it will exert the maximum baffling effect.

3rd. Avoid sharp bends or other severe mechanical strains in manufacturing and installing.

4th. Use oil of a quality to make the dielectric loss fairly low.

Appendix I

Theory of Energy Loss in a Pair of Leaky Condensers in Series

A pair of leaky condensers in series may be represented for purposes of calculation by a pair of perfect condensers in series, each condenser being shunted by a non-inductive resistor.

Consider a pair of perfect condensers having capacities c_1 and c_2 and a pair of resistors having resistances r_1 and r_2 arranged as in Fig. 2, and suppose a sinusoidal e. m. f. of E volts to be imposed between the terminals A and C.

Let
$$a_1 = (2\,\pi\,f\,r_1\,c_1)^2 \tag{1}$$
$$a_2 = (2\,\pi\,f\,r_2\,c_2)^2 \tag{2}$$

Then the power factors of the parts $A\,B$ and $B\,C$, will be as follows:

$$k_1 = \frac{1}{\sqrt{1/a_1 + 1}} \tag{3}$$

$$k_2 = \frac{1}{\sqrt{1/a_2 + 1}} \tag{4}$$

and the sines of the power factor angles will be as follows:

$$s_1 = \frac{1}{\sqrt{a_1 + 1}} \tag{5}$$

$$s_2 = \frac{1}{\sqrt{a_2 + 1}} \tag{6}$$

Let i_1 and i_2 be the currents in r_1 and r_2 respectively and I_1 and I_2 the currents in c_1 and c_2 respectively. Then the total power loss will be:

$$W = i_1^2\,r_1 + i_2^2\,r_2 \tag{7}$$

Let Z_1 and Z_2 be the impedances from A to B and B to C, respectively. Then

$$Z_1 = r_1\,s_1 \tag{8}$$
$$Z_2 = r_2\,s_2 \tag{9}$$

and the total impedance from A to C equals

$$Z = \sqrt{(Z_1\,k_1 + Z_2\,k_2)^2 + (Z_1\,s_1 + Z_2\,s_2)^2}$$
$$= \sqrt{Z_1^2 + Z_2^2 + 2\,Z_1\,Z_2\,(k_1\,k_2 + s_1\,s_2)} \tag{10}$$

Combining **8** and **9** with **10**

$$Z^2 = r_1^2\,s_1^2 + r_2^2\,s_2^2 + 2\,r_1\,r_2\,s_1\,s_2\,(k_1\,k_2 + s_1\,s_2) = \frac{r_1^2}{a_1 + 1} + \frac{r_2^2}{a_2 + 1} + 2\,r_1\,r_2\,\frac{1 + \sqrt{a_1\,a_2}}{(a_1 + 1)\,(a_2 + 1)} \tag{11}$$

As the drop from A to B is the same in amount by either parallel path and as the drop from B to C is the same in amount by either parallel path

$$i_1\,r_1 = \frac{I_1}{2\,\pi\,f\,c_1} \text{ or } I_1 = i_1\,\sqrt{a_1} \tag{12}$$

$$i_2\,r_2 = \frac{I_2}{2\,\pi\,f\,c_2} \text{ or } I_2 = i_2\,\sqrt{a_2} \tag{13}$$

If I be the total current through the circuit

$$I = E/Z = \sqrt{I_1^2 + i_1^2} \tag{14}$$
$$I = E/Z = \sqrt{I_2^2 + i_2^2} \tag{15}$$

Combining **12** and **14**

$$E/Z = \sqrt{i_1^2\,(a_1 + 1)}$$

and combining **13** and **15**

$$E/Z = \sqrt{i_2^2\,(a_2 + 1)}$$

whence

$$i_1^2 = \frac{E^2}{Z^2\,(a_1 + 1)} \tag{16}$$

$$i_2^2 = \frac{E^2}{Z^2\,(a_2 + 1)} \tag{17}$$

Inserting the values from **16** and **17** in **7**

$$W = E^2\,\frac{\dfrac{r_1}{a_1 + 1} + \dfrac{r_2}{a_2 + 1}}{Z^2} \tag{18}$$

Combining **18** with **11**

$$W = E^2\,\frac{\dfrac{r_1}{a_1 + 1} + \dfrac{r_2}{a_2 + 1}}{\dfrac{r_1^2}{a_1 + 1} + \dfrac{r_2^2}{a_2 + 1} + \dfrac{2\,r_1\,r_2\,(1 + \sqrt{a_1\,a_2})}{(a_1 + 1)\,(a_2 + 1)}} \tag{19}$$

It is of interest to note that if $a_1 = a_2$ the above equation reduces to

$$W = \frac{E^2}{r_1 + r_2} \tag{20}$$

indicating that the loss, in this case, is the ohmic loss due to leakage current only.

The power factor $\cos\,\theta$ may be derived as follows:

By definition

$$\text{Cos } \theta = \frac{W}{E\,I} = \frac{W\,Z}{E^2} \tag{21}$$

Combining equations **18** and **21**

Cos θ =

$$\frac{\dfrac{r_1}{a_1 + 1} + \dfrac{r_2}{a_2 + 1}}{\sqrt{\dfrac{r_1^2}{a_1 + 1} + \dfrac{r_2^2}{a_2 + 1} + \dfrac{2\,r_1\,r_2\,(1 + \sqrt{a_1\,a_2})}{(a_1 + 1)\,(a_2 + 1)}}} \tag{22}$$

Appendix II

Power Factor of Heterogeneous Insulation

A non-homogeneous dielectric consists of a mixture of particles of different resistivities and specific capacities. When a potential difference is established across such a dielectric, it sets up both displacement and conduction currents. At the boundaries between particles of different resistivities and specific capacities, the current may change from a conduction to a displacement current, or vice versa, just as at the plates of a condenser, the current changes from a displacement current into a conduction current as it leaves the dielectric and enters the plates. The total $i^2\,r$ loss may therefore be due not only to the leakage current but also to local conduction currents generated in particles of the insulation by the displacement currents.

A homogeneous dielectric may be represented by a capacity shunted by a resistance. When alternating voltage is applied across such a dielectric, the only energy loss that occurs is the $i^2\,r$ loss due to that portion of the current which passes through the resistance and this is the same for direct as for alternating currents.

A non-homogeneous dielectric may be represented by two or more shunted capacities in series. In the case of a dielectric consisting of two elements, if one of these capacities is high and the shunted resistance of the other is low, most of the current will pass inductively through that capacity and conductively through that resistance causing a high ohmic loss in the latter. This loss constitutes the major part of the dielectric loss and can occur only with alternating current.

It was shown in Appendix I that the power factor of two leaky condensers in series may be represented by the following equation:

Cos θ =

$$\frac{\dfrac{r_1}{a_1 + 1} + \dfrac{r_2}{a_2 + 1}}{\sqrt{\dfrac{r_1^2}{a_1 + 1} + \dfrac{r_2^2}{a_2 + 1} + \dfrac{2\,r_1\,r_2\,(1 + \sqrt{a_1\,a_2})}{(a_1 + 1)\,(a_2 + 1)}}} \tag{22}$$

The quantities a_1 and a_2 in this equation each contains the product of the resistance and capacity of one of the elements of the dielectric. But this product may be expressed in terms of resistivity ρ_1 or ρ_2 and specific capacity K_1 or K_2 by the following well known relations:

$$\left\{\begin{aligned} r_1\,c_1 &= \frac{\rho_1\,K_1}{36\,\pi \times 10^{11}} \\ r_2\,c_2 &= \frac{\rho_2\,K_2}{36\,\pi \times 10^{11}} \end{aligned}\right. \tag{23}$$

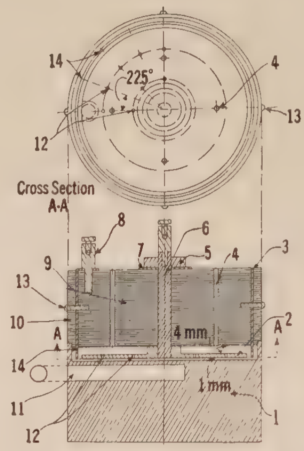

Fig. 7—Electrolytic Cell for Liquid Insulation

No	No Req.	Material	Description
1	1	Brass	Bowl 9.4 cm. in diameter with lip 9 mm. high & 2 mm. in thickness (see 11)
2	1	"	Circular plate 8 cm. dia. 2 mm. thick with collar 1.6 cm. dia. 4 mm. thick (see 12)
3	1	"	Cylinder 8.4 cm. inner dia. 1 mm. thick., axial length = 4 cm., with flap for binding post.
4	4	—	Holes bored through "9" parallel with axis, at radial distance of 5 cm. 2 mm. dia.
5	1	Brass	Nut to same thread as "6"
6	1	Steel	Pin 6 mm. dia. 5.2 cm. long threaded upper end to fit "5" & drilled & tapped to take "8"
7	1	Brass	Washer 3.5 cm. dia., center hole 6 mm. dia. 1 mm. thick.
8	2	"	Binding posts 1.25 cm. long & 6 mm. dia. (wire hole 2.5 mm. dia.)
9	1	Insul. Material	Circular block, axial length 3.8 cm. 8.4 cm. dia. (see 4)
10	1	"	Ring. axial length 4 cm. & 4 mm. thick with flange cut out bottom end 3 mm. deep to fit "1"
11	1	—	Thermometer hole bored 5.8 cm. deep & 8 mm. dia.
12	8	—	Holes bored through "2". 1 mm. dia. at radial distance of 1.5 cm. from center
"	16	—	Holes bored through "2". 1 mm. dia. at radial distance of 3 cm.
13	4	Brass	Screws. 1 cm. long
14	16	—	Vent holes. 1 mm. dia.

Inserting these values in equations (**1**) and (**2**):

$$\left\{\begin{aligned} a_1 &= \left(\frac{f\,\rho_1\,K_1}{18 \times 10^{11}}\right)^2 \\ a_2 &= \left(\frac{f\,\rho_2\,K_2}{18 \times 10^{11}}\right)^2 \end{aligned}\right. \tag{24}$$

If, as is approximately the case in impregnated paper, the thickness of the two elements, paper and oil, averages about equal, the resistances r_1 and r_2 may be replaced by resistivities ρ_1 and ρ_2. Hence, equation (**22**) may be expressed as follows:

Cos θ =

$$\frac{\dfrac{\rho_1}{1 + a_1} + \dfrac{\rho_2}{1 + a_2}}{\sqrt{\dfrac{\rho_1^2}{1 + a_1} + \dfrac{\rho_2^2}{1 + a_2} + \dfrac{2\,\rho_1\,\rho_2\,(1 + \sqrt{a_1\,a_2})}{(1 + a_1)\,(1 + a_2)}}} \tag{25}$$

If ρ_1 and ρ_2 are as great as they are usually found to be, the *ones* may be omitted without appreciable error, the equation then reducing to the following simple form.

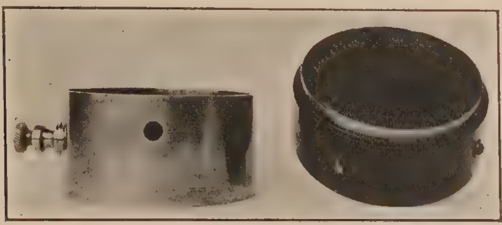

FIG. 8

$$\operatorname{Cos} \theta = \frac{A_1^2/\rho_1 + A_2^2/\rho_2}{A_1 + A_2} \tag{26}$$

Where $A_1 = \dfrac{18 \times 10^{11}}{f K_1}$

$A_2 = \dfrac{18 \times 10^{11}}{f K_2}$

Appendix III

CELL FOR RESISTANCE AND CAPACITY MEASUREMENTS

The resistivity of petrolatum was determined by measurements of a film 1 mm. thick and 8 cm. in diameter. The design of the cell, in which measurements were made, is shown in Fig. 7, and its appearance in Fig. 8.

The general arrangement of the testing circuit is shown in Fig. 9. With this apparatus the resistivity of an oil can be determined over a range of temperature from 30 deg. cent. to 105 deg. cent. in three-quarters of an hour.

The heating of the cell is accomplished by placing it on an electric hot-plate. With a reasonably sensitive galvanometer a sufficiently great deflection can be obtained to ensure an accuracy of 10 per cent. This may seem to be a large error, but the authors have known cases where different laboratories, using different types of cells, could not check such measurements within 50 per cent.

Capacity measurements were made with direct current by the ordinary ballistic galvanometer method, and with alternating current by a new method involving the use of a guard ring. The diagram of connections is shown in Fig. 10. C_1 is the cell connected in the Wheatstone bridge circuit. The resistance R_g is in series with the guard ring of the cell to prevent a serious arc in case the oil should fail under the application of voltage. The detector G is a Weibel electromagnet moving-coil galvanometer. The mutual inductance M, the resistance R and the capacity C are parts of the moving-coil circuit of the galvanometer and serve to stabilize the deflections and to produce critical damping. The shield circuit, R_s and C_3, was adjusted by connecting the galvanometer to post A and varying R_3 until the galvanometer showed no deflection when the key K was reversed. After this

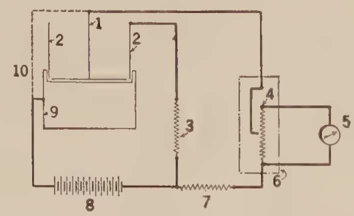

FIG. 9—DIAGRAM OF CONNECTIONS—RESISTIVITY OF OILS
1. Upper electrode of resistivity cell.
2. Guard ring of resistivity cell.
3. Jagabi resistance 2000 ohms.
4. Ayrton galvanometer shunt.
5. Galvanometer.
6. Paraffine slab under Ayrton shunt.
7. Megohm.
8. Battery of dry cells.
9. Lower electrode, bowl of resistivity cell.
10. Connection for obtaining constant of galvanometer.

adjustment had been made the bridge could then be accurately balanced by connecting the galvanometer to the post B and varying the resistance R_1.

For measuring the specific capacity of oil, a substitution method was used. The first balance was obtained with only air in the cell and then a second balance with the oil in the cell. The ratio of R_1 obtained in the first balance to that obtained in the second balance, is the specific capacity of the oil.

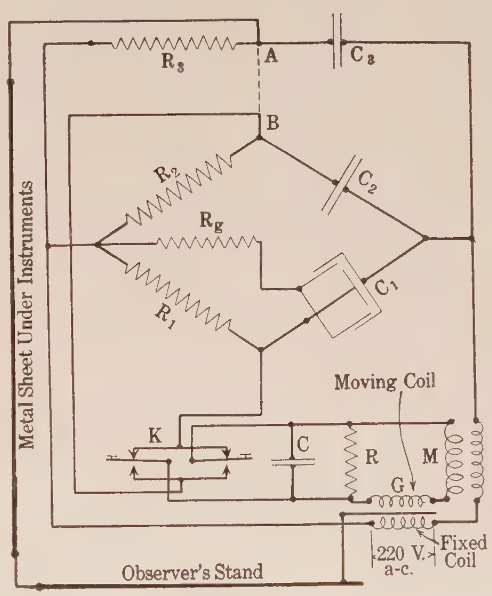

FIG. 10

To check the accuracy of the method, the capacity of the cell with air was measured by substituting for the cell a condenser of known value. The measured capacity was found to be 0.000099 microfarads as compared with 0.000098 microfarads calculated from the dimensions of the cell.

The specific capacity of an oil could be measured over a temperature range of 30 deg. to 105 deg. cent. in an hour with an accuracy of about 3 per cent.

Temperature Limits in Large Machines

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Fellow, A. I. E. E.
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Review of the Subject.—*The present Institute standards allow a maximum limit of 105 deg. for fibrous insulation and 125 deg. for mica insulation with an allowance of 150 deg. subject to special guarantees of the manufacturer. In high-voltage machines of large size, the effect of actual copper temperatures higher than 105 deg. may cause softening and disappearance of binding materials, bulging of insulation, and consequent powdering of insulation under periodic pounding of copper on softened material, and ionization at voids so created.*

Operating experience of four large size machines demonstrated the above effects to repeatedly take place in machines operating at copper temperatures of 150 deg. cent. None of these effects were noted in machines operating at copper temperatures of 105 deg. cent. or under. Two machines have safely operated for over three years at maximum copper temperatures of 130 deg. cent. Incorrect conclusions may be made as regards the safe temperature limits by judging the performance of machines unless actual copper temperatures are known. Lower ambient temperatures and fractional loads may reduce the operating temperatures 25 to 35 deg. below the assumed limits.

Machines designed for high temperatures are less efficient than machines designed for cool temperatures, in one instance the difference being as great as several hundred kilowatts at all loads.

The calculation of ventilation of large machines is relatively uncertain; it is of importance to aim at a conservative limit rather than set it too near the danger point.

From the standpoint of economy as well as greater safety, it appears that large machines should not be operated at higher copper temperatures than 105 deg. cent. This means that with outside air ventilation seldom exceeding 20 deg., the maximum standard limit with the standard reference of 40 deg. ambient should be 125 deg. equivalent to 85 deg. maximum rise at the copper. In all cases where the room air is close to 40 deg. the maximum copper rise should be limited to 65 deg.

Other correlated and important features discussed incidentally in the paper are the typical proportionality of life at different temperatures for fibrous insulation, and the new tentative conventional allowance for reducing to maximum copper temperature, readings taken outside the insulation.

CONTENTS

Introduction

In response to the request of the Electrical Machinery Committee that I prepare this contribution, I will review the actual temperatures experienced with machines in service and some of the essential features which must be given due weight in the interpretation of such experiences.

The two limits established by the Institute are 105 deg. cent. for fibrous insulation, and 125 deg. cent. or mica insulation, with an allowance of 150 deg. cent. for the latter, subject to special guarantees of the manufacturer. As the established standard ambient temperature is 40 deg. cent., the designer is allowed for his machine a maximum temperature rise at any point on the copper of 65 deg. for fibrous insulation and 85 deg. for mica insulation, with an optional 110 deg. rise, subject to special guarantee.

These are the outstanding and essential bases of A. I. E. E. rating.

In former years, it was the practise to use a double standard of rating, allowing a rise of 50 or 55 deg. for normal loads, and 70 or 75 deg. for overloads, equivalent, for modern machines, to 90 or 95 deg. temperature limit for normal loads and 110 or 115 deg. for overloads.

The writer introduced, fifteen years ago, the method of single rating for turbo-generators which, in the following years, became generally used.[1] In 1914 the Institute adopted the single rating for a larger class of apparatus like motors, transformers, etc., adopting the aforesaid temperature limits for the two classes of insulation.

This was done with the object of simplifying the problem for the manufacturer and the user of apparatus. In substance, the limit of 105 deg. adopted for fibrous insulation was arrived at by striking an approximate average between the two former limits of 90 to 95 deg. for normal loads and 110 to 115 deg. for overloads; the limit of 110 deg. for mica insulation with the optional 150 deg. limit was intended to apply principally to large turbo-generators and large machines.

Considerable objection was raised to the adoption of single rating for commercial motors and in some cases for central station apparatus.

It is not my object here to take any sides in the dispute, which is apparently becoming smoothed out and adjusted.

Note:—(All temperatures given in this paper refer to actual copper temperatures and degrees Centigrade.)

1. "The standard ratings of Westinghouse alternating turbo-generators are based on two different methods of determining capacity:

First. A rating with gurantees covering performance at normal loads and definite overloads, momentary peak loads being within the guaranteed overload capacity.

Second. A rating corresponding to the maximum safe operating capacity of the particular machine in question, with no guaranteed overload capacity.

This method of maximum rating originated with the New York Edison Company and, though comparatively new, has much in its favor." (The Westinghouse Diary for 1912, page 23.)

To be presented at the Annual Convention of the A. I. E. E. Niagara Falls, Ontario, June 26-30, 1922.

It is more important to present a comprehensive survey of the relations, as they now can be ascertained, which have existed in practise between the rated temperature limits and the actual temperatures sustained by the apparatus in service.

Before doing this, it is important to approximately define the relations which different stresses, due to voltage, temperature and time, vibration and mechanical stresses, bear to the life of the insulation.

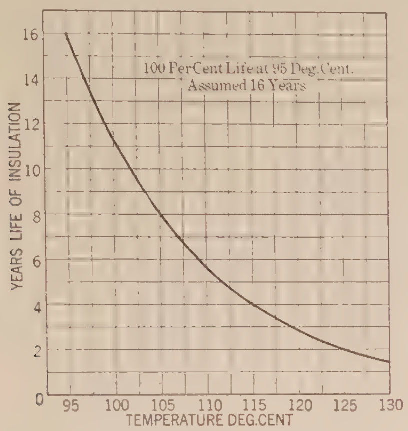

FIG. 1—LIFE CURVE OF FIBROUS INSULATION AS AFFECTED BY TEMPERATURE

EFFECT OF VOLTAGE

It is now a well recognized fact that all insulating materials, including mica, will be destroyed by ionization, if any air voids are present in the insulating covering of an electrical conductor and the potential gradient at these points exceeds the limit of about 75 volts per mill. Imperfections in the material like small iron impurities, will also cause distortions of potential gradients and accentuate the danger of ionization or reduce the effective thickness of insulation. It follows, therefore, that as a general rule the experience with life of insulating materials is only applicable within the limits of voltage of the apparatus investigated.

EFFECT OF TEMPERATURE AND TIME

Up to a few years ago, there was an impression in the minds of operating people that a machine rated for 110 or 115 deg. two- or three-hour overload— would operate safely if the overload was limited to two or three hours *in each day* but would be rapidly destroyed if the overload was carried for much longer periods in one day. The fact that these short overload periods usually covered the occasional peak requirements took away from the operators the inducement to study more closely what higher temperatures would have prevailed if the occasional overloads had been carried for more than two or three hours, and what would have been the effects on the insulation.

In recent years considerable progress has been made in coordinating the relations which exist between temperature, time of application and resultant deterioration and shortening of life. In a paper presented before the Institute in February, 1921, I gave abstracts of results of the classic tests of the British Engineering Standards Committee of 1905, and extended the discussion to experiments made on paper insulation and the observation of considerable investigation of conditions of paper insulation used in cables subjected to occasional high temperatures. At the same meeting D. W. Roper presented results of similar observations, while Fisher and Atkinson gave an experimental formula for determining the reduction of life strength of paper subjected to different temperatures. From these and other studies made on fibrous insulation, it is possible now to plot a characteristic curve of the effect of temperature upon the life of fibrous insulation if not otherwise affected by ionization or mechanical stresses. While the actual years of life at different temperatures are not established by experience, the relative proportionality of the length of life may safely be represented by the relation given by the curve in Fig. 1. This tentative curve would roughly indicate that, other things being equal, a machine operating at 105 deg. will have a life of 50 per cent of a similar machine operating at 95 deg. Similarly, if we operate a machine 90 per cent of the time at 95 deg. and the remaining 10 per cent of the time at 115 deg., the life of the machine will be 77 per cent of the virtual life at 95 deg. for 100 per cent of the time. From this law we can now more clearly see how the double rating may have practical advantages.

From similar studies on mica insulation, there appears to be no doubt that aside from the influence of ionization due to voltage and mechanical stresses, mica insulation can safely withstand almost indefinitely high temperatures probably as high as 200 deg.

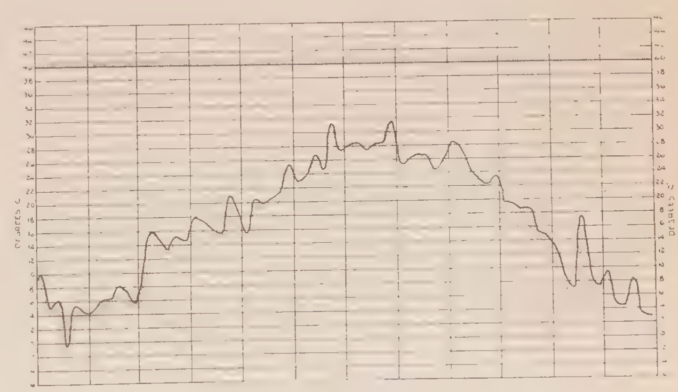

FIG. 2—FIVE-DAY AVERAGE OF MAXIMUM AIR TEMPERATURES IN NEW YORK CITY FOR THE YEAR 1921

EFFECT OF VIBRATION AND MECHANICAL STRESSES

Vibrations are obviously always present in rotating machinery due to movement and reactions of the rotating elements and the periodic pounding of the insulation due to the drag of the rotating field and the abnormal heavy blows under system short circuits, etc. With well wrapped and unimpaired insulation and well supported coils, these stresses will not affect

the elastic limits of the materials, but if the copper temperature is high, the varnishing materials in the insulation may distill and loosen the binder, allowing a play for the copper to pound and powder the insulation as a continuous drop of water will hollow out a stone. Stresses in the insulation are also imposed by different rate of expansion and contraction of the copper and the insulation under large changes of temperatures which may cause bulging and voids in the insulation between the insulating slots, with consequent ionization if the voltage stresses are sufficiently high.

The possible damages to insulation due to vibrations and mechanical stresses are, therefore, to be looked for mainly in machines of large power and relatively high voltages where ionization may ensue. From the coexistence, in large power machines, of high temperatures with high voltages, failure may be caused either by bulging of insulation due to uneven expansion and contraction, or powdering of insulation due to softening and disappearance of the varnishing materials.

Where only low pressures of around 110 volts are present, relatively high temperatures like 110 deg. for fibrous insulation do not appear to destroy the usefulness of the insulation. Where voltages are high, the mechanical stresses must be seriously considered for temperatures higher than 105 deg. for all types of insulation.

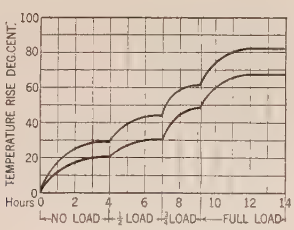

Fig. 3—Characteristic Temperature Rise of Two Generators from No-Load to Full Load

Operating Experience

In analyzing practical experience of life of insulation on electrical apparatus, it is very important that weighty consideration be given to the foregoing three characteristic factors of service. We would be in error to conclude that because satisfactory results were obtained with certain limiting temperatures in a certain class of machines, similar service could be obtained in other classes of machines.

One of the greatest difficulties in making comparisons of practical experience with apparatus in different installations is the uncertainty of the actual temperatures which have actually prevailed in the machine.

The most common error made by engineers discussing temperature limits is to assume that a machine rated for say 105 deg. if insulated with fibrous materials, or 150 deg. if insulated with mica, because it has operated successfully for a number of years, therefor 105 deg. or 150 deg. have proved satisfactory in practical service. Nothing can be further from the truth than such assumptions.

The machine may be cooled by air usually 10 to 20 deg. lower than the 40 deg. standard ambient. Fig. 2 gives the five-day averages of maximum daily air temperature for 1921 in New York City. These show, at a glance, the large margin between the actual maximum temperature throughout the year and the assumed 40 deg. base of reference.

The machine may never have carried the rated load, so that instead of the 65 and 110 deg. rises allowed for the full rated loads, the actual rises in operation at partial loads may have been 10 or 15 deg. less. Fig. 3 shows characteristic temperature rises for two machines from no-load to full load. As large turbo units are operated at the most economical point at 75 per cent to 80 per cent of full rating, the actual rise in operation at those loads may be at least from 10 to 15 deg. less than at full rating.

The result of these and other variable conditions of service is that the actual temperatures sustained by the machine may have been 25 or 35 deg. lower than the assumed limits. As the vast majority of the machines operate under such conditions, it becomes of vital importance that when we speak of temperature limits, we clearly state whether we mean the actual temperature or an arbitrary figure assumed for purposes of commercial ratings and arrived at by striking a reasonably safe limit, which, on account of the aforesaid service conditions, it is not expected to be reached in practise by the vast majority of the machines. If in applying the results of our experience we will eliminate from consideration all machines which, while nominally rated at say 105 deg. or 150 deg., in practise have only operated at 20 or 30 deg. below those limits, we will come to consider only relatively few cases where actual temperatures of 105 or 150 deg. have really obtained.

Only from the experience of such machines can we derive conclusions as to safe temperature limits.

The maximum copper temperatures of the machines in the following illustrations were obtained either by direct copper temperature measurements or by adding to the highest reading of the thermometer detectors between coils an allowance calculated on the basis of 2½ per cent of that rise over the inlet air for each thousand volts of the rated voltage of the machine. This correction seems to be as close as we can ascertain from elaborate tests which are under way under the auspices of manufacturers and large users.

In interpreting these records, it must be remembered that these maximum temperatures were present only during the period of peak load less than four hours a day, and generally of much shorter duration. For the balance of the time, the copper temperatures were lower than the indicated maximum, mainly on account of lower loads and sometimes on account of lower temperature of the inlet air.

Fig. 4 gives the log of maximum temperatures sustained by one turbo-generator, which has had several failures, and Fig. 5 the log of maximum temperatures representative of three turbo generators, two of which have had several failures. The characteristic features of these failures were either bulging insulation, powdering of filler and mica at edges of copper windings or overheating of iron laminations.

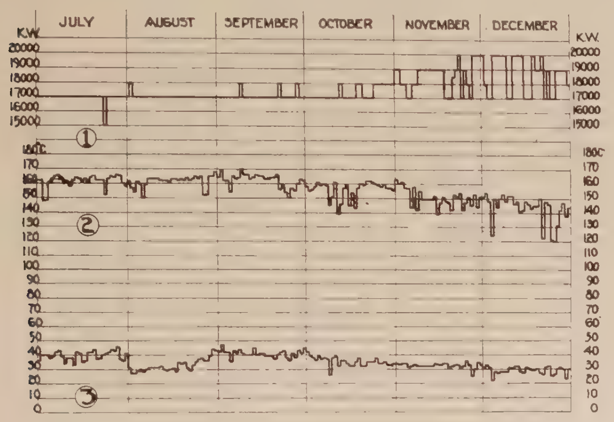

Fig. 4—Characteristic Operating Conditions

21,000-kv-a., 1500-rev. per min., 11,000-volt generator
(1) Daily maximum kw. load
(2) Daily maximum copper temperature
(3) Inlet air temperature
For failures, see curve of machine *A* in Fig. 6.

The records of coil burn-outs of the three machines which had failures are graphically plotted in Fig. 6 in reference to total hours of service between failures. The third machine of the same type as *B* and *C* operated under the same conditions of service without failures, though when the coils were removed they showed the same characteristic features of impaired insulation.

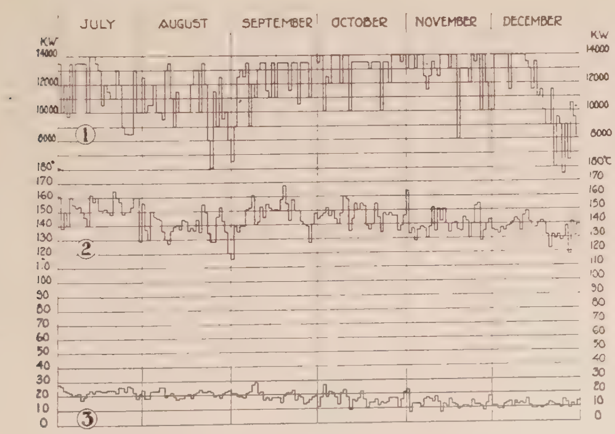

Fig. 5—Characteristic Operating Conditions

For three 19,000-kv-a., 1800 rev. per min., 8000-volt generators
(1) Daily maximum kw. load
(2) Daily maximum copper temperature
(3) Inlet air temperature
For failures of two units, see Curves of machines *B* and *C* in Fig. 6

The records of failures of machines designed for high temperatures could be extended, but the writer was not able, within the very short limits of time allowed for the preparation of this paper, to secure the necessary details of operating temperatures and hours of service to make the presentation complete as in the case of the three machines *A*, *B* and *C*.

In Fig. 7 are given the maximum copper temperatures representative of five machines, one of which has operated for eight years, two for over two years and two for five months, without failures.

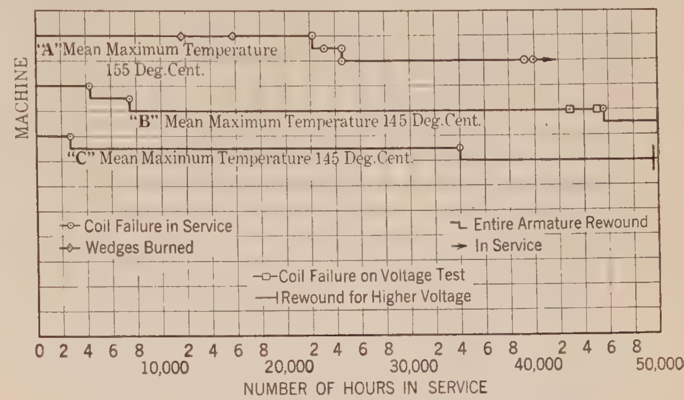

Fig. 6—Record of Generator Coil Failures

Machine *A*—21,000-kv-a., 1500-rev. per min., 11,000 volts
Machines *B* and *C*—19,000 kv-a., 1800-rev. per min., 8000 volts
Refer to Figs. 4 and 5 for operating conditions

In Fig. 8 are given the maximum copper temperatures representative of two machines which have operated from three to four years without failures.

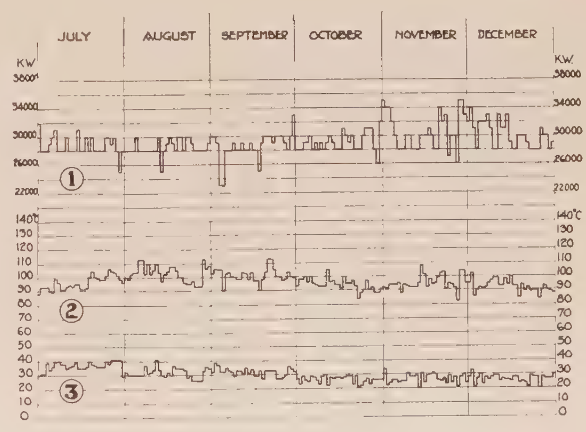

Fig. 7—Characteristic Operating Conditions

For four 35,000-kv-a., 1500-rev. per min., 11,000-volt generators
one 30,000-kv-a., 1500-rev. per min., 11,000-volt generator
(1) Daily maximum kw. load
(2) Daily maximum copper temperature
(3) Inlet air temperature
No coil failures have occurred on these machines.
One in service for eight years, two for two years, and two for five months.

These data cover varied experiences with large machines of different manufacturers.

Deductions From Experience

From this experience it appears that we would be justified in concluding that mica insulation would not safely withstand temperatures of 150 deg. in high-

voltage turbo-generators. This conclusion would seem to be in disagreement with the often repeated statement that mica insulation on the original Niagara generators safely withstood temperatures as high as 185 deg. for a long period of years. If, however, we apply to that experience the consideration of the three factors with which I prefaced this presentation, and recollect the special circumstances of the Niagara case, involving heavy copper bar windings in a generator armature of relatively smaller length than in large turbo-generators, relatively smaller kw. power per pole, relatively slower speed, and a very moderate pressure of 2200 volts, we would conclude that these conditions are so essentially different from the conditions existing in a modern large size, high-speed, high-voltage generator that such experience is of no real value in our problem.

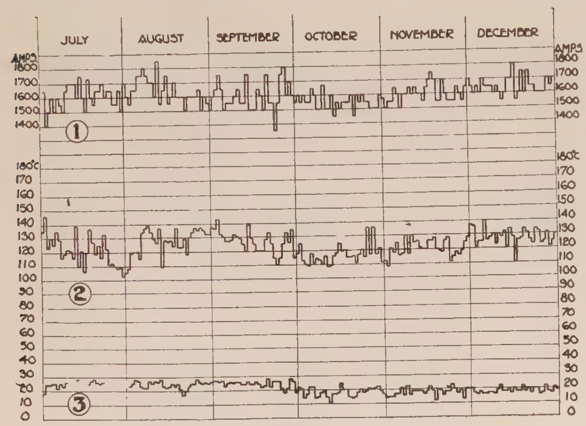

FIG. 8—CHARACTERISTIC OPERATING CONDITIONS

For two 35,000-kv-a., 1200-rev. per min., 12,000-volt generators
(1) Daily maximum amperes load
(2) Daily maximum copper temperature
(3) Inlet air temperature
No coil failures have occurred on these machines.
In service three and four years.

The experiences I have reviewed should lead us to the conclusion that maximum copper temperatures of not exceeding 105 deg. for mica insulation in high-voltage turbo-generators should give safe operation. Temperatures around 150 deg. are unsafe. It is probable that some higher maximum temperature than 105 deg. might prove satisfactory. To what extent the limit of 105 deg. might be safely raised is a question which cannot be definitely settled in the light of the experience available.

ENGINEERING AND ECONOMICAL CONSIDERATIONS

Having arrived at the conclusion that, with the present knowledge, about 105 deg. should be the limiting copper temperature in large machines, the question arises whether it is practical and economical to impose such a limit on the industry.

From an engineering standpoint, there appears to be no difficulty in building 105 deg. generators larger than required for the largest size steam turbines that have been produced for the two speeds of 1200 and 1500 revolutions. For the 1800- and 3600- rev. per min. speeds, the 105 deg. generators are today close to the limits of the steam turbines, *i. e.*, about 8000 kv-a. and 35,000 kv-a. at 85 per cent power factor for 6000-kw. and 30,000-kw. steam turbines. If improvements in the steam turbine will make it feasible to increase the capacity of the 3600- and 1800-revolution turbines, it seems reasonable to expect that corresponding improvements will also be made to permit the construction of correspondingly larger generators without increasing the temperature limit.

There is, therefore, no engineering obstacle to the adoption of about 105 deg. limiting temperature for the largest sizes of machinery now built. There remains only to be considered the question of economy. Does the 105 deg. limit make the cost of the machine unjustifiably high?

Unquestionably, a machine designed for a high temperature is cheaper than a machine designed for a cool temperature. A difference of say 25 deg. may make a sensible difference in cost. On the other hand, the machine designed for a cool temperature will be more efficient than the machine designed for a high temperature. It is difficult to evaluate in dollars per kilowatt to what extent these differences will affect the net results.

For an approximation, I would make a rough guess that the purchaser would be justified in paying $1 per kilowatt more for the cooler machine for the saving in higher efficiency.[2] This would leave the purchaser the net advantages of the greater factor of safety of the machine designed for cool operation.

As to the manufacturer, I cannot state how far the $1 would go to cover the increased cost of the cool operating machine especially if, in large size machines, he should be compelled to use more and higher quality iron and more copper and insulating materials. However, the fact that machines of large sizes designed for cool temperatures are commercially produced and

2. From tests for losses and efficiency of two generators under load conditions, using the air measurement method, are obtained the following comparative results:

Machine No. 1, having a temperature rise at maximum load of 120 deg., gave the following efficiencies of generator:

½ Load	91.9 per cent
¾ Load	93.8 per cent
Full Load	94.9 per cent

Machine No. 2, having a temperature rise at maximum load of 80 deg., gave the following efficiencies of generator:

½ Load	94.6 per cent
¾ Load	96.1 per cent
Full Load	96.8 per cent

The total losses of machine No. 1 exceed those of machine No. 2, as follows:

½ Load	331 kw.
¾ Load	389 kw.
Full Load	405 kw.

Even allowing for inaccuracies in the method of measurement, the results illustrate the point that, at least in this case, the cool machine had a materially higher efficiency than the hot machine. While with other machines the differences may not be as great, they will undoubtedly be of sufficient value to produce a sensible saving at the coal pile in the operation of the cool machine.

marketed would seem to indicate that the 105 deg. limit does not impose unjustifiably high costs of manufacture.

The result of these considerations is that while nominally the machine designed for cool temperature is somewhat more expensive to build than a machine designed for high temperature, its slightly increased cost is more than balanced by its greater efficiency and greater reliability.

Value of Greater Reliability

There is undoubtedly general agreement that, other things being equal, a machine designed for cool temperature is safer than a machine designed for high temperature. To find the value of this greater safety we must consider that with the rapid growth of the central station industry, two new factors are becoming of primary importance.

One is, that with increased size of generating units and fewer of them in a station, it becomes imperative to obtain a greater factor of safety. Also, with the expansion of the systems and superpower line interconnections over large areas, the load factors on the generating plants tend to increase, requiring longer service from each generating unit.

The other is that, with the development of new plants improvements always become available in the art, like utilization of higher steam pressures, higher superheat, higher boiler economy, less heat losses in gases, better economy of auxiliaries and better heat balance. To secure the economy of this better efficiency, new generating units in old as well as new stations must be operated to carry the base loads of the system while the older units are operated to carry the balance of the loads of shorter duration. Therefore, the burnout of an armature in a modern generator is vitally serious, not so much for the damage and cost of repairs, but mainly for the loss of business, if it cripples the system, at the time of peak loads, and the increased cost of operation of older and less economical units while the large new unit is out of service for repairs. With prevailing prices of coal, the failure of a large unit may cause a loss in production costs alone of $500 to $600 a day for each day the machine is out of service for repairs. If the failure also happens at a time when the service would have to be crippled, the losses would be incalculably serious.

Conclusions

Central station managers are keenly alive to the necessity of securing the most reliable apparatus to safeguard their interests and the interests of the public they serve. Designers must approach the problem of producing machines of highest reliability. Central station engineers should cooperate with the manufacturers in standardizing for all bidders the same limit of temperature so as to place the competitive business on equal terms. The present Institute rule which specifies 85 deg. copper rise for mica insulation but also allows 110 deg. cent. subject to special guarantees is not right. Only one standard should be adopted for the best interests of all concerned. The limiting copper rise of 85 deg., which corresponds to the present *conventional* limiting temperature of 125 deg. for the *conventional* 40 deg. standard ambient temperature, appears to be the maximum safe limit dictated both by reasons of economy and safety. With this conventional limit of 125 deg. it should be understood that in practise it would be expected that the temperature of the inlet air would be around 20 deg. instead of 40 deg. so that the actual operating temperature would be about 105 deg. In all special cases where the inlet air is near 40 deg., as with machines in Fig. 4 and Fig. 7, the rise should be limited to about 65 deg. instead of 85 deg.

The manufacturer, in taking a conservative stand on such an important question, must also consider the practical point that the calculation of the ventilation of a large machine is relatively uncertain so that the results may be several degrees higher than calculated. It becomes, then, of practical importance to aim at a lower limit to permit of some higher variations to which the user may adjust himself without requiring expensive changes, rather than to set the limit too near the danger point so that any higher deviation would necessitate derating the machine or subjecting it to early failures.

A NEW TRAFFIC LIGHT

Various systems of traffic or signal lights have been installed during recent years in order to care for the ever-increasing traffic on city streets at night. These have consisted of elevated beacons which are also used to control traffic; iron, wooden and concrete posts equipped with illuminated globes at their tops; illuminated signs, etc.

A recent development in a traffic signal that is discernible by day and by night is the Mushroom traffic light. This signal was first used in Milwaukee, and since then units of this type have been installed in many other cities, including Chicago, Cleveland, Minneapolis, Indianapolis, Detroit, St. Louis, Kansas City and many smaller cities.

This new traffic light consists of an 18-inch heavy ruby glass hemisphere covered by a ribbed steel grating rising eight inches above the pavement. Its hemispherical shape causes the wheels of passing vehicles accidently striking it to slide off easily without injury either to the light or to the vehicle. In this type of unit there is no part to be broken off by impact. Two 75-watt lamps are used.

This light is designed primarily for use in the center of street intersections, especially at intersections where traffic is heavy but where a policeman is not regularly stationed. Its presence in the street ahead immediately denotes to the motorist a busy corner. By dividing the traffic and keeping motorists on the proper side of the thoroughfare, the possibility of accidents is, of course, greatly reduced.

Features of Main Power House Transformers for Queenston Plant

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Review of the Subject.—*Interest in the main step-up transformers for the New Queenston generating station of the Hydro-Electric Power Commission of Ontario centers largely about their great physical size and the heavy short-circuit currents to be dealt with. Physically they are the largest single-phase transformers in operation today. In spite of the fact that they are for 25-cycle service, to our knowledge even their kv-a. rating is exceeded by only one bank of single-phase transformers now in operation, namely, the 70,000-kv-a., 60-cycle bank at the Colfax Station of the Duquesne Light Company.*

Figures are given for the weights and dimensions of these transformers and their component parts as well as the performance calculated from test results.

The mechanical forces in 25-cycle transformers are inherently high because of the relatively large number of turns necessary to develop the voltage, and because of their relatively low impedance to the flow of short-circuit currents. As the forces depend upon the square of the ampere-turns, it is evident that both the above conditions contribute materially toward increasing the forces.

To understand the bracing necessary to withstand the electromagnetic forces developed under short-circuit conditions, it is necessary to understand the nature of these forces as well as their magnitude.

The nature and magnitude of the mechanical forces existing between current carrying coils are discussed, (1) for a single turn coil in space, (2) for two single turn coils arranged concentrically and lying in the same plane, (3) for two single turn coils arranged coaxially and lying in parallel planes.

The conclusion is reached that as long as primary and secondary coils are adjacent there is no limit on the shape of the coil from the mechanical point of view, as all stresses acting in the plane of the coils are neutralized and there is therefore no force of any magnitude tending to distort the coils. The conclusions reached when single turns are considered hold equally as well for coils or groups of coils, so that in considering the forces in a transformer these fundamentals must always be kept in mind.

Thus by interleaving the primary and secondary coils, it is possible to overcome completely any limitations which the mechanical forces with other arrangements of coils may dictate and to choose a coil shape which adapts itself most readily to the solution of the other important problems of the design, namely, insulation and ventilation.

The Queenston transformers employ the interleaved type of construction familiarly known as the shell form, with rectangular pancake coils forming the alternating groups of primary and secondary coils.

The distribution of the mechanical forces in these transformers is analyzed in detail. The effects of imperfect distribution of turns and of taps are shown to be very undesirable. All of the required voltages could have been obtained with considerably fewer leads and taps but the reduction in the insulation difficulty through the elimination of extra leads would have been accompanied by an increase in the mechanical forces due to unbalancing conditions on tap connections. In these transformers the maximum stress occurs on the first under voltage tap and has a value equal to 136 per cent of the maximum stress with the full winding.

Having analyzed the various types of forces to be met with in the design of transformers of this type of construction, it will be interesting to examine the mechanical supports which have been provided in these units.

The proper ventilation and insulation of a transformer is equally as important as the adequate mechanical support of the winding. The system of bracing used in these transformers is particularly interesting, in that, in spite of the substantial construction used, the other vital factors of ventilation and insulation have not been impaired in the least.

CONTENTS

Introduction

In the years 1909 and 1910 there were designed, built, and installed at the Niagara Falls substation of the Hydro-Electric Power Commission of Ontario, the first nine 3000-kv-a. water-cooled transformers, to raise the three-phase power from 12,000 volts to a nominal transmission line potential of 110,000 volts. The data available at that time for designing, building and operating 110,000-volt apparatus were rather meager.

Six years later, in 1916, there were installed in this same substation the first three 7500-kv-a. transformers having the same characteristics. Six years of experience with the original units on the Hydro-Electric Power Commission's system with many data from other sources, made the problem of designing and building the 7500-kv-a. units relatively a much simpler one.

Interest in the main step-up transformers for the new Queenston generating station of the Hydro-Electric Power Commission of Ontario centers largely about their great physical size and the heavy short-circuit currents to be dealt with. Physically they are the largest single-phase transformers in operation today. In spite of the fact that they are for 25-cycle service, to our knowledge, even their kv-a. rating is exceeded by only one bank of single-phase transformers now in operation, namely, the 70,000-kv-a., 60-cycle bank at the Colfax station of the Duquesne Light Company.

The design of transformers of such great capacity requires the solution of many difficult mechanical problems. This phase of the design is particularly difficult when the transformers must be made self-protecting against the short-circuit stresses incident to a 25-cycle system of the magnitude contemplated for this development. Planned for an ultimate capacity of some

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fifteen 45,000-kv-a. generators, the Queenston station will be among the largest ever projected.

Physical Dimensions and Weights

A few statistics as to the physical size of these units might be of interest. They have a nominal rating of 15,000-kv-a. output at 80 per cent power factor delivered at 63,500 volts with 12,000 volts impressed. To compensate for the drop through the transformers under the above load condition, the open-circuit voltage is 67,200 volts. They have a maximum rating of 16,500 kv-a. under the same conditions of loading as given above with a guarantee of 55 deg. cent. rise in temperature as measured by change in resistance.

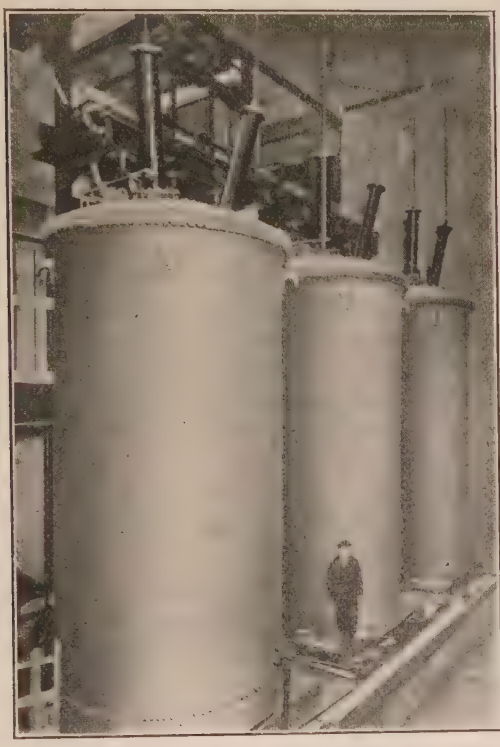

Fig. 1

They are operated in banks of three, delta-connected on the low-voltage side, star-connected on the high-voltage side, to step up the generated power from a nominal voltage of 12,000 volts to transmission line potential. Taps are provided on the high-voltage windings so that the line potential may be varied between 110,000 to 132,000 volts.

The windings contain over 11,000 pounds of copper and the magnetic core contains over 60,000 pounds of punchings. The bare transformer weighs 99,000 pounds. The case, cover, base and various accessories weigh 46,500 pounds. Complete, with oil, the unit weighs 205,500 pounds.

Owing to the large dimensions and the great weights of the parts, especially cores and tanks (see Figs. 1 and 18), methods of handling at the manufacturer's plant and at the site of the power house as well as transportation facilities had to be considered in laying out the design.

The case is a cylindrical boiler plate shell, 9 ft. 6 in. outside diameter, and stands 21 feet from the rail to the flange at the top. The height from the rail to the top of the high-voltage terminal is slightly over 28 feet. The great height of the transformer is partly on account of the crowned cover and bottom which were necessary to meet the requirement of 150 lb. per sq. in. pressure, or 24 inches of vacuum, test on the tank. The bare tank with cover weighs 28,000 pounds. The tanks were delivered complete on the power house site.

The heaviest pieces are the transformer cores (Fig. 18). Ready for shipment they measure 7 ft. 2 in. by 7 ft. 4 in. floor space by 12 ft. 4 in. from floor line to top of insulating washers. Each core was shipped complete as shown in Fig. 18, except that the terminal supports were removed. The windings and insulation having been thoroughly dried and treated, the cores were sealed in oil in a special shipping tank. The shipping tank, oil and core weighed 142,000 pounds. At the manufacturer's plant and at Queenston the cores were handled with special lifting rigs by overhead cranes.

At Queenston the transformer cores were transferred directly to the main tanks, and flooded with oil. This procedure obviated the necessity of any drying and treating of the windings or insulation after installation, furthermore it greatly reduced the time required to put the units into actual service.

Rating and Performance

The Hydro-Electric Power Commission of Ontario required these transformers to be rated to develop 63,500 volts when delivering 15,000 kv-a. at 80 per cent power factor, with 12,000 volts applied to the low-voltage terminals at 25 cycles, and further that they would operate successfully with as high as 13,200 volts applied without excessive no-load current and losses.

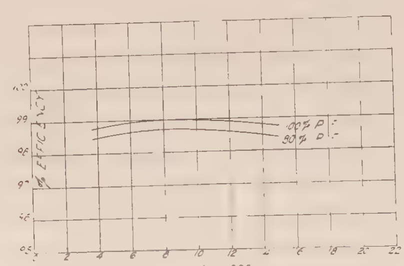

Fig. 2.—Efficiency Curves

With the above rating the transformers have a regulation of 5.85 per cent. This gives current rating of the windings as follows: 236 amperes for the high voltage, 1320 amperes for the low voltage. All tests to determine the performance of these units were made with above current values.

Complete tests to determine the no-load and full-load losses, also temperature runs with full-load current and voltage in the windings by the opposition method, have been made at works of the Canadian Westinghouse Company, Limited. All temperatures

of windings were determined by the increase in resistance method. The results obtained from temperature runs indicate that with full kv-a. output under normal voltage and frequency with 45 imperial gallons (54 U. S.) of water per minute through the cooling coils, the temperature of the windings will not exceed 68.5 deg. cent. or a temperature rise of 43.5 deg. cent. above ingoing water at 25 deg. cent.

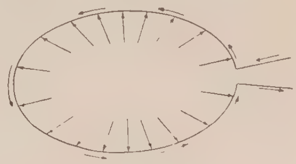

Fig. 3

Fig. 2 indicates the efficiency of these transformers at 100 per cent and 80 per cent power factor, calculated from the measured no-load iron losses and full-load wattmeter copper losses at 75 deg. cent.

Importance of Mechanical Problem

The mechanical forces in 25-cycle transformers are inherently high because of the relatively large number of turns necessary to develop the voltage, and because of their relatively low impedance to the flow of short-circuit currents. As the forces depend upon the square of the ampere-turns, it is evident that both the above conditions contribute materially toward increasing the forces. Frequently the conditions under which a transformer operates are such that external impedance considerably reduces the magnitude of the short-circuit currents which can flow through the transformer. On small systems advantage can frequently be taken of this external impedance to make the transformer good for the conditions under which it has to operate without making it capable of sustaining a short circuit with full voltage maintained. The usual interpretation of the phrase "self-protecting" is to consider the worst case possible, namely with full voltage maintained.

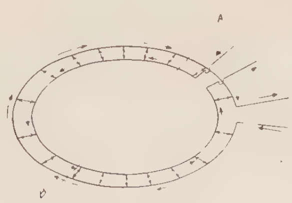

Fig. 4

On large systems only very slight advantage can be taken of external impedance owing to the great concentration of power. With systems of the capacity of the Niagara system, a further complication arises from the limitation in the amount of current which can safely be interrupted by the circuit breakers.

Frequently it will be found advisable so to group the machines and busses as to limit the amount of current which can flow into a fault to an amount which will be within the breaker capacity. This was the case in the layout of the Queenston station so that some slight advantage could be taken of the fact that generators and their respective transformers will never operate in parallel without reactors between the units. The greater the capacity of the individual transformer banks on a system in proportion to the total generating capacity, the greater becomes the difficulty of making them fully self-protecting and the less becomes the necessity for their being made so.

Nature of Forces in Transformer Coils

To understand the bracing necessary to withstand the electromagnetic forces developed under short-circuit conditions, it is necessary to understand the nature of these forces as well as their magnitude. Consider first a single circular turn of wire carrying current. If the leads enter the turn along a radius their effect may be neglected and the forces on this turn are due only to the reaction between the various elements of the turn upon one another; thus as illustrated in Fig. 3, the forces acting are all radially outward from the center of the coil and are equally distributed around the circumference of the coil.

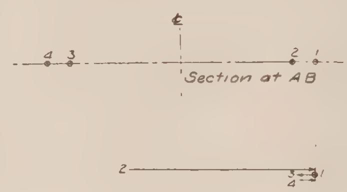

Fig. 5

That the effect of the leads may always be neglected becomes clear when it is remembered that, in the usual case, the coil will consist of a large number of turns instead of a single loop and the forces on portions of the coil will be many times those which can exist between the entering leads. Now consider two concentric circular turns lying in the same plane, and carrying equal currents. The forces are still radial as shown in Fig. 4, with two cases to be considered, first, currents in two turns in phase and second, currents in two turns out of phase. The forces illustrated in Fig. 4 are for the condition of the currents being out of phase by 180 deg. as would be the case between a primary and secondary winding. The forces between the two turns are repulsive and tend to keep them concentric. If the current were in phase in the two coils the forces would become attractive and any eccentricity would tend to increase the force at the point of least separation until the two turns are finally brought into contact.

To analyze this case more closely consider a section *A B* of the two turns shown in Fig. 4. Fig. 5 shows conditions at this point. For convenient reference, the different conductors have been numbered and the direction of flow of current is indicated in the conventional manner. There is a strong repulsion between conductors 1 and 2 due to their proximity and a re-

pulsion of the same order of magnitude between conductors 3 and 4. These are not the only forces acting, however. Conductor 1 is attracted by conductor 3 and repelled by conductor 4. The magnitude of these forces compared with the magnitude of the forces between conductors 1 and 2 is inversely as the distances between

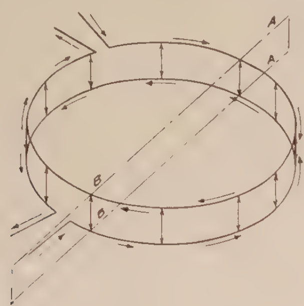

FIG. 6

them. Thus, when the diameter of the circles is great in comparison with their separation the forces on conductor 1 due to conductors 3 and 4 are in opposite directions and of very nearly the same magnitude. The excess of the attraction toward conductor 3 over the repulsion from conductor 4 slightly decreases the repulsion between conductors 1 and 2. By this process of reasoning it may be clearly demonstrated that the only forces which need be considered are those between adjacent coil sides.

The other common grouping of windings employed in transformer construction is the inter-leaved grouping in which all coils are coaxial and primary and secondary groups alternate with one another across the opening in the magnetic core. The mechanical forces between windings arranged in this manner are radically different from what they are with the concentric construction. Refer to Fig. 6, in which the turns are of the same diameter and lie in parallel planes. Fig. 7 shows a cross-section looking in the direction *A B* indicated in Fig. 6. The direction of the various forces acting is shown by the arrows. On any conductor there are three forces acting. For example on conductor 2 there are a strong force of repulsion from conductor 1, a very much weaker force of repulsion from conductor 3,

FIG. 7A

FIG. 7B

and a force of attraction toward conductor 4 of the same order of magnitude as the repulsion from conductor 3. The horizontal component of the attraction 2-4 practically wipes out the repulsion 2-3, and its vertical component detracts only slightly from the repulsion 1-2. The net result is that the only force of magnitude is that between conductors 1 and 2 and all forces acting in the plane of the coils are practically neutralized.

The conclusion is reached that as long as primary and secondary coils are adjacent there is no limit on the shape of the coil from the mechanical point of view, as all stresses acting in the plane of the coils are neutralized and there is therefore no force of any magnitude tending

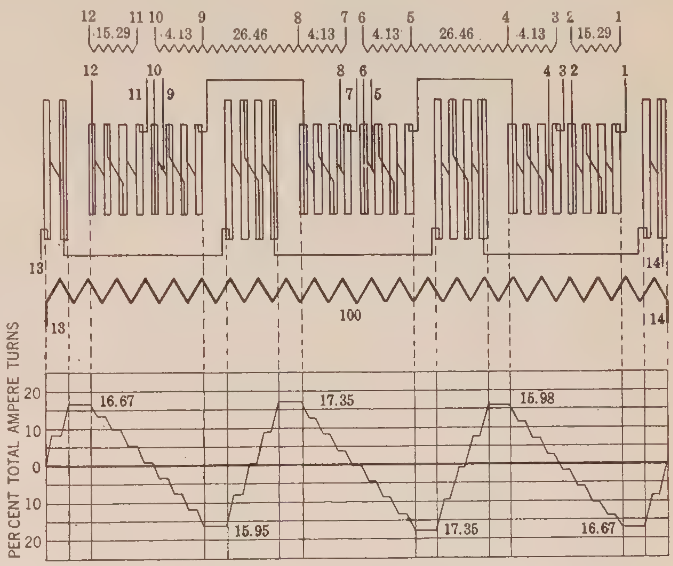

FIG. 8

to distort the coils. The conclusions reached when single turns are considered hold equally as well for coils or groups of coils, so that in considering the forces in a transformer these fundamentals must always be kept in mind. Thus by interleaving the primary and secondary coils, it is possible to overcome completely any limitations which the mechanical forces with other arrangements of coils may dictate and to choose

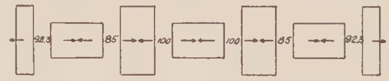

FIG. 9

a coil shape which adapts itself most readily to the solution of the other important problems of the design namely, insulation and ventilation.

DISTRIBUTION OF FORCES IN QUEENSTON TRANSFORMERS

The Queenston transformers employ the interleaved type of construction familiarly known as the shell form, with rectangular pancake coils forming the alternating groups of primary and secondary coils. The interlacing may be indicated symbolically *L H H L-L H H L-L H H L* there being three groups of high-voltage coils with which are associated a group of low-voltage coils on either side. This arrangement is called a 6-*H-L* grouping from the number of spaces high to low voltage which occur in the transformer. Fig. 8 shows a view of the top of the transformer, on which are indicated the connections and the develop-

ment of winding. The figures adjacent to the development indicate the percentage of the total series turns in each section. Below the plan view has been plotted a graph of the magnetomotive force causing leakage across the opening between primary and secondary. The flux density will be proportional to the m. m. f. so that the same chart might represent induction just

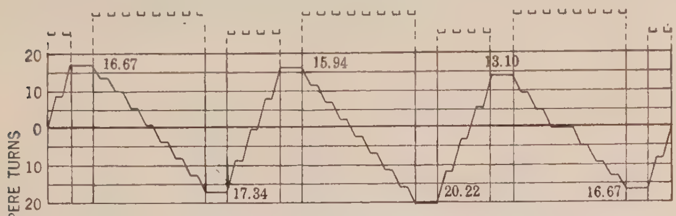

Fig. 10

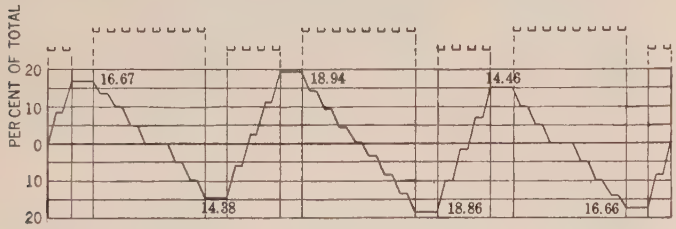

Fig. 11

as well as m. m. f. It will be noted that the flux density rises to a peak value at each *H-L* space. When it is possible to equalize the ampere turns in all groups the value of all of these peaks will be identical and other conditions being the same, the magnitude of the repulsion at each *H-L* space will be the same. It is frequently impossible to get an exact balance and in such cases the magnitude of the repulsion at different *H-L* spaces will differ slightly. For example, refer to Fig. 10 and note the values of the ampere turns across

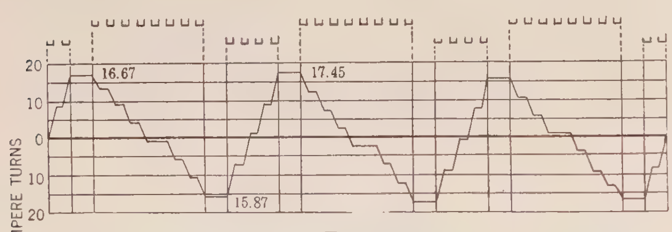

Fig. 12

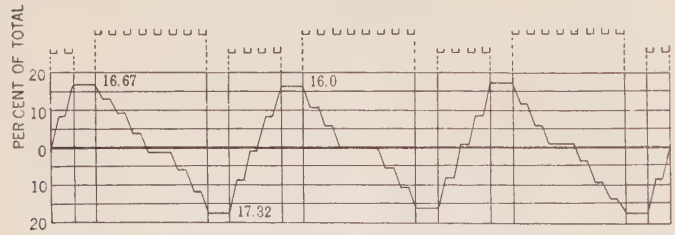

Fig. 13

various *H-L* spaces are + 16.67, − 15.98, + 17.35, − 17.35, + 15.98 and − 16.67 respectively. The total force against the end groups of coils is that due to the maximum value of ampere turns concentrated across any *H-L* space. This follows from the fact that each of the internal groups has a force acting against its opposite faces in opposite directions. Since the magnetic centers of all groups lie in the same plane, the resultant of two such forces is the algebraic difference. If there is an excess of one force above the other, it is transmitted to the next group and combines with the forces developed there. Referring to Fig. 9 the force against either face of the middle group of high-voltage coils is due to 17.35 per cent of the total ampere turns. The reaction against the adjacent low-voltage coils is of course of equal magnitude. If we call this force 100 per cent then the force developed in the next *H-L* space will be $(15.98/17.35)^2 \times 100$ or 85 per cent and in the outermost *H-L* spaces will be $(16.67/17.35)^2 \times 100$ or 92.3 per cent. Cancelling out opposite forces of equal magnitude it will be seen that the stress of the end group of low-voltage coils against the supports is due to the highest stress in any part of the windings.

100 per cent − 85 per cent = 15 per cent unbalanced force which adds to reaction of 85 per cent against right face of outer high-voltage group giving 100 per cent.

100 per cent − 92.3 per cent = 7.7 per cent unbalanced which adds to reaction of 92.3 per cent against right face of outer low-voltage group giving 100 per cent.

Effect of Taps

Taps always result in unbalanced magnetic conditions unless equal turns are cut out simultaneously from each group. This would lead to a very large number of taps

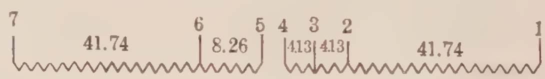

Fig. 14

and leads and in most cases the complication could not be justified. However, it should always be borne in mind that the greater the percentage of the winding tapped, the greater is the possibility of increasing the forces by unbalancing. Fig. 10 shows the magnetomotive force distribution on the first under voltage tap and Figs. 11, 12 and 13 under the other tap conections.

All of the required voltages could have been obtained with considerably fewer leads and taps as for example with the development of winding shown in Fig. 14 but the reduction in the insulation difficulty through the elimination of extra leads would have been accompanied by an increase in the mechanical forces due to unbalancing conditions on tap connections. As will be noted from Figs. 8 and 11 to 13, the maximum stress in the Queenston transformers occurs on the first under voltage tap and has a value of $(20.22/17.35)^2 \times 100 =$ 136 per cent of the maximum with the full winding.

Force on Individual Conductors or Coils

Fig. 15 shows an enlarged section of one portion of Fig. 8. It will be noticed that the individual coils which make up this group do not lie in fields of equal intensity. In fact the field intensity increases almost uniformly from one edge of the group to the other, reaching a maximum value at the edge of the space *H* to *L*. To obtain the total force developed between any two groups the ampere turns in that group must be multiplied by the average flux density through the group. Since the field intensity increases uniformly the average will be one-half the maximum. It is almost self evident that the coils nearest the *H-L* space will develop the greatest repulsion owing to the intense field in which they lie. It is a simple matter to calculate the percentage of the total force developed in a given group, which is concentrated against the face of any particular coil. For example, the number of turns in the high-voltage coil nearest the low-voltage

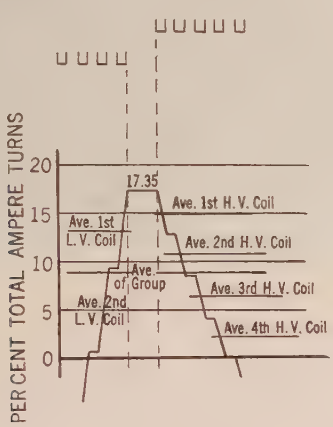

Fig. 15

winding is $4.41/17.35 \times 100 = 25.4$ per cent of the total number of turns in that group. The average field intensity throughout this coil in per cent of the average field intensity for the whole group is

$$\frac{17.35 - \frac{4.41}{2}}{8.62} \times 100 = 175.6 \text{ per cent.}$$

The percentage of the total stress developed against the first high-voltage coil will then be $0.254 \times 1.756 \times 100 = 44.6$ per cent. Similarly the second high-voltage coil is subject to

$$\frac{4.41}{17.35} \times \frac{10.735}{8.62} \times 100 = 31.6 \text{ per cent, and the}$$

third high-voltage coil to

$$\frac{4.41}{17.35} \times \frac{6.325}{8.62} \times 100 = 18.6 \text{ per cent, and the}$$

fourth high-voltage coil to

$$\frac{4.13}{17.35} \times \frac{2.065}{8.62} \times 100 = 5.7 \text{ per cent, of the}$$

total force in that group.

In the same way it can be shown that the force against the first and second low-voltage coils is approximately 75 per cent and 25 per cent respectively of the total force developed in the group.

The spacing strips which separate the coils to form the ventilating ducts must give the coils ample support to withstand safely the highest value of stress that can be concentrated against it. The problem resolves itself

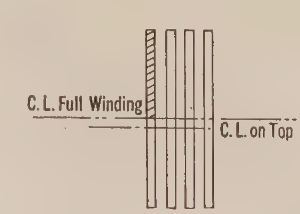

Fig. 16

into a question of supporting each individual turn frequently enough to limit the deflection under short-circuit stress to an amount which the coils can safely stand. This limit is set as much by the amount of bending which the insulation will stand without breaking, as it is by the elastic limit of the copper itself.

Effect of Displaced Electromagnetic Centers

Tapping a coil will always result in locally unbalanced conditions. This applies equally as well, regardless of whether we are speaking from the electrical or the mechanical point of view. From the design point of view, taps are always very undesirable. The mechanical effect of taking a tap out of a group of coils is illustrated in Fig. 16, which shows the worst possible unbalancing due to a single tap in a group of four coils. With one-half of the turns in one coil idle, the shift in electromagnetic center lines would be 3.67 per cent of the width of the coil. Obviously the conditions would be worse with fewer coils in the group, the worst case being a single coil. The ideal arrangement would be where the electromagnetic center lines are maintained coincident under all possible combinations of connec-

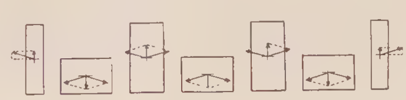

Fig. 17

tions. This ideal condition can be realized even when the design is handicapped by taps, provided the taps can be arranged to come at the connection between coils. Reference to Fig. 8 will show that on these transformers for the Queenston station, this problem has been successfully worked out so that the taps all come from connections between coils. In this way the possible displacement is limited to that obtainable with good manufacturing tolerances.

When a displacement in center lines exists, the total force in the various planes parallel to the face of the coils may be resolved into components parallel and perpendicular to the plane of the coils. Fig. 17 shows

a section through the upper ends of the coils of a transformer in which the displacement has been exaggerated to illustrate the nature of these stresses. With the displacement in the direction assumed the resultant forces are upward at the center of each low-voltage group and downward at the center of each high-voltage group

Fig. 18

of coils. Conditions are repeated at the lower ends of the coils so that the total vertical forces will be double those indicated in Fig. 17.

Method of Bracing Employed

Having analyzed the various types of forces to be met with in the design of transformers of this type of contruction, it will be interesting to examine the mechanical supports which have been provided in these units.

First to consider the total horizontal force perpendicular to the faces of the coils. Those portions of the coils which pass through the laminated core are securely held in place against these stresses by the punchings themselves. It is only necessary to supply supports for the portion which projects beyond the iron. Heavy steel plates are placed against the ends of the assembled groups of coils and insulation. By means of tie rods these plates are clamped about the ends of the coils to secure them against possible movement. Fig. 18 shows clearly the steel plates and the tie rods spanning them. Three rods are used on either side, two of the upper and one of the lower being visible in the picture. The others are concealed by the structural steel end frames but the holes provided to tighten these are clearly shown.

The weight of all the coils and insulation is carried on supports which are independent of the stacked up punchings which form the magnetic core. This support consists of two T beams with heavy spreader bolts between. One beam is inserted into each end of

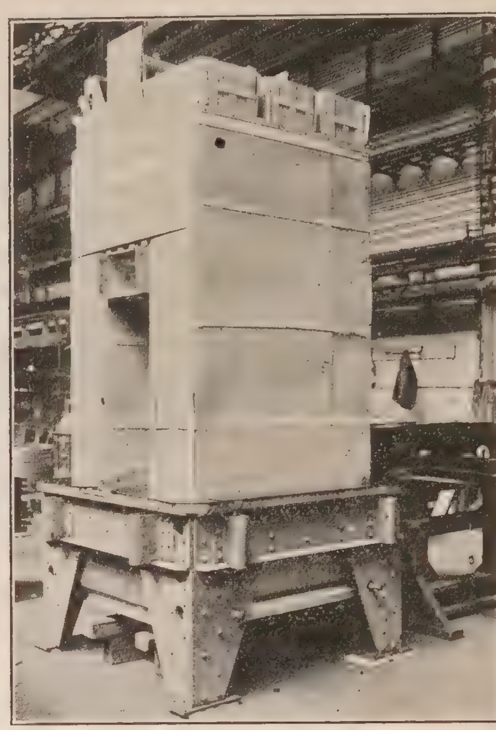

Fig. 19

the opening through the coils. By means of the spreader bolts at each end of the beams they are forced apart until the opening in the coils is solidly blocked, and all the weight transferred to the lower supporting frame. Fig. 19 shows the lower T beam in position ready for the building of the coil, the photograph being

Fig. 20

taken on a unit of slightly different rating and characteristics. The T beams in the case of these transformers are made of phosphor-bronze in order to eliminate stray losses as they parallel a portion of the magnetic circuit. Fig. 18 also shows quite clearly this construction. These T beams also take care of any vertical

stresses due to possible discrepancies in the electromagnetic centers of the primary and secondary coils.

Individual coils are braced by the use of specially designed spacing strips. The vertical portions are supported by "wavy" spacing strips which support each turn at frequent intervals without blanketing any portion of the coil. The group of wavy strips in any duct is cleated together at several places and the cleats dovetail into the channels over the edge of the coils so that the strips cannot shift. The corners and the ends of the coil are braced by means of the ventilated spacers shown in Fig. 20. These spacers are formed of micarta in such a way that a solid piece of material is obtained having ribs at an angle to its length and open spaces between the ribs. The slant of the ribs is sufficient to support every turn crossing the spacer and still allow the free passage of oil through the spacing strip. By properly arranging these spacers they can be made to direct the flow of oil into and out of the ducts along natural stream lines.

The proper ventilation and insulation of a transformer is equally as important as the adequate mechanical support of the winding. The system of bracing used in these transformers is particularly interesting, in that in spite of the substantial construction used, the other vital factors of ventilation and insulation have not been impaired in the least. Over 70 per cent of the area of each coil lies along a vertical duct in which direction the resistance to the flow of oil is a minimum. The velocity of oil flow under these conditions is very high and the swerving oil stream by its vigorous action scours off the stagnant film of oil adjacent to the coil itself, and thereby reduces the temperature difference between the copper and the oil. This temperature drop at the surface of the coil is one of the most important elements of temperature difference going to make up the total difference in temperature between the windings and cooling water. It falls into that division of the temperature rise which responds almost instantly to changes of load and therefore has a most important part in determining the ability of the transformer to carry overloads.

Description of the 45,000-kv-a. Queenston Generators

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Both of the Canadian General Electric Company, Ltd.

Review of the Subject.—*Notwithstanding the very large rated capacity of the 45,000-kv-a. generators for the Queenston power house of the Hydro-Electric Power Commission of Ontario, their essential construction features are not different from those of much smaller rated generators. The generators are of the vertical shaft type with two guide bearings, and a thrust bearing. The thrust bearing is located above the stator and carries the weight of the complete rotating elements of the generator and water turbine. Each generator is provided with a direct-connected exciter.*

The flywheel effect required for satisfactory speed regulation of the turbines necessitated the use of auxiliary flywheels mounted on the shaft adjacent to the generator rotor. The rotor is constructed with a number of cast steel wheels which together form the rotor spider for carrying the pole pieces. The pole pieces are made of punchings and are attached to the rotor with three dovetails per pole. The coils are made of copper strip wound on edge.

The stator frame is split vertically into three sections to conform with foundry and shipping limitations but the core is built up without being split. The stator windings consist of form-wound, diamond-shaped coils, each slot containing two coil sides. The coils are made of stranded conductor and are insulated with mica tape, which affords more or less flexible insulation. The ends of the coils are braced against the distorting effect of severe short circuits in such a manner as to permit expansion and contraction of the copper without injury to the mica insulation. The armature phase connections are made with bus rings supported from the stator frame, making all connections accessible.

CONTENTS

THE purpose of this paper is to describe briefly a few of the construction features of the 45,000-kv-a. generators manufactured by the Canadian General Electric Company for the Queenston power house of the Hydro-Electric Power Commission of Ontario. Because of the fact that the rated capacity of these generators is greater than that of any generators ever before constructed, there is a tendency to create an impression that their construction would involve radical changes from the more or less familiar types of much smaller generators, but aside from one or two requirements peculiar to this installation, the problems presented in the design of these generators involved no great difficulties or departure from what has been considered standard construction. In fact if our power station engineers should find that larger generators could be used advantageously it is possible to build generators having capacities of 60,000 or 75,000 kv-a.

To be presented at the A. I. E. E. Annual Convention, Niagara Falls, Ontario, June 26-30, 1922.

at moderate speed without departing from ordinary methods of construction, or meeting with excessive costs per kv-a.

General Description

These generators are of the vertical shaft type with revolving fields and stationary armatures. They have two guide bearings and a thrust bearing. A substantial base ring supports the stator frame and carries the spider bracket for the lower guide bearing. The thrust bearing is supported by a deck or spider spanning the top of the stator frame and carries the rotating parts of the generator and turbine. There is a direct-connected exciter mounted at the top of the generator. A general view of the complete unit is shown in Fig. 1. The generators are designed to deliver three-phase, 25-cycle current at 12,000 volts, and rotate at a speed of 187½ revolutions per minute. The full-load rating is 45,000 kv-a. at 80 per cent power factor, with a temperature rise not exceeding 65 deg. cent. as observed by detectors imbedded in the slots of the stator core or by resistance measurements of the stator or rotor windings. The full-load efficiency including all mechanical and electrical losses is guaranteed to be not less than 97¾ per cent at 100 per cent power factor. The exciters are rated 150 kw. at 250 volts.

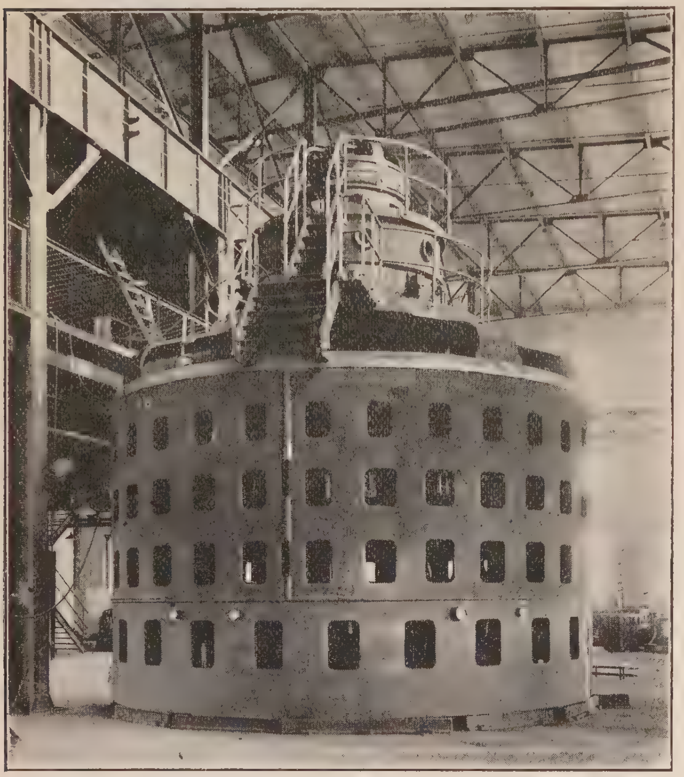

Fig. 1—General View of the Assembled Unit

Stator Frame, Core and Windings

The stator frame is divided into three sections vertically, in order to keep the weight within the foundry capacity and provide sections of a size and weight that could be easily handled in the shop and in transportation. These castings are probably the largest in size and weight ever used for generator construction, the frame being 24½ ft. in diameter by 10 ft high, and weighing, complete, approximately 90 tons. In building the core of such a large generator it is desirable to avoid joints that divide the core into sections because looseness and vibration of the laminations are liable to develop due to the unequal expansion of the frame and core, and the difficulty in arranging clamps capable of exerting sufficient pressure. Therefore it was decided to build up the core in the power station thus obtaining a continuous ring. The slots in the stator core are unusually large for a waterwheel type generator, being as large as those commonly used in the large high-voltage turbo-generators. The stator winding is of the common "Barrel" type with two coil sides per slot. Each turn of the coils is insulated with mica tape applied by hand after the coil has been formed. The coil insulation consists of mica tape put on by hand with a special compound sticker between layers.

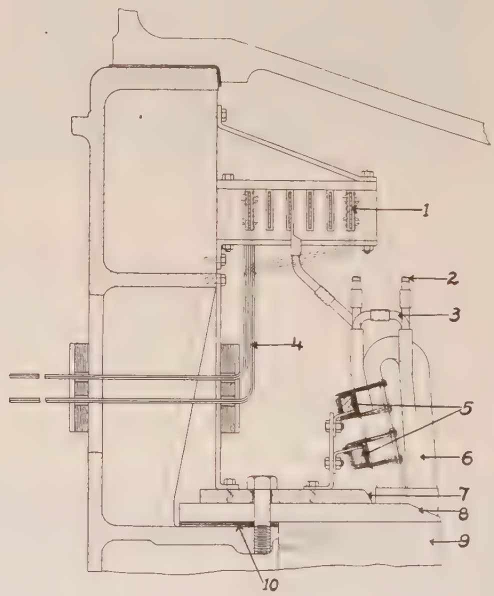

Fig. 2—Arrangement of Stator Coil Connections and Coil Bracing Rings

1. Phase bus rings.
2. Pole connections.
3. Group connections.
4. Terminal leads.
5. Bracing rings.
6. Stator coil.
7. Clamping flange of core.
8. Clamping fingers.
9. Punchings or core.
10. Removable shims to allow taking up settling of core.

This process results in a uniform insulation on the full length of the coil and when slightly heated a sufficient flexibility is obtained to permit the removal and assembly of coils without great danger of damage to the insulation. The semi-plastic condition of the insulation also permits the expansion and contraction of the copper, due to changes in temperature, with a

minimum disintegrating effect on the mica in the insulation.

Stator Coil Supports

The projecting ends of the coils at both the top and bottom are braced against one another by small wooden spacers, placed between the sides of the coils,

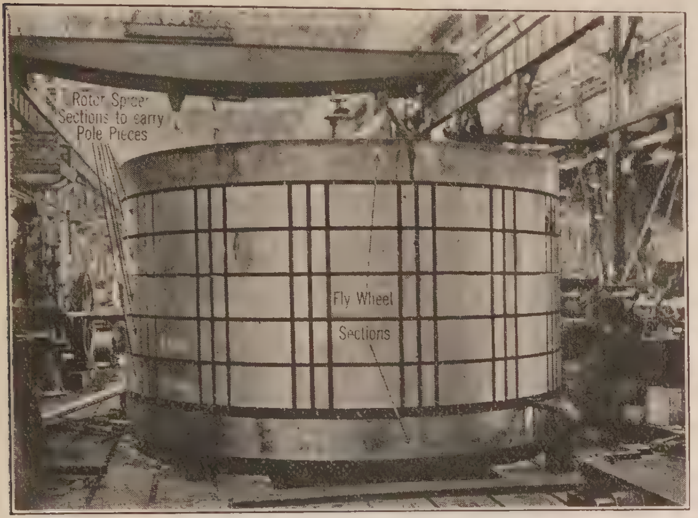

Fig. 3—The Rotor

and the whole winding is supported at each end, against the distorting effect of short circuits by two complete steel rings which are supported from the frame by suitable iron brackets. The windings are bound securely to the supporting rings with treated cord. This method of binding permits of a certain amount of flexibility that is desirable to allow for the expansion and contraction of the coils due to changes in temperature. The bracing rings are covered with insulating material not only for insulating purposes but to act as a cushion for the coils to rest against, and to take the sharp blows resulting from severe short circuits without cutting the coil insulation.

Potential Wave

The stator coils are chorded to take advantage of fractional pitch properties in obtaining a voltage wave form as near as possible to the ideal sine wave, and to eliminate the objectionable harmonics.

Armature Conductor

The section of copper necessary to carry the current in the stator windings being too large to use a single strand, the conductor was subdivided into a number of strands of small section to facilitate the forming of the conductor in the coils and also to reduce largely the eddy current losses in the copper. The phase connections of the stator winding have been taken care of in a rather unusual manner by the use of a bus ring arrangement supported from the inside of the stator frame. The connections between these bus rings and the windings are made with flexible connections which can be disconnected. This arrangement allows free access to all the connections for cleaning and inspection, and permits the removal of damaged coils without disturbing the connections.

Ventilation

Air for cooling the generator is admitted to the pit beneath it, through ducts from outside the station, or from the generator room, and is drawn into the machine by the blower action of the rotor. The air is expelled through the openings in the stator frame into a chamber surrounding the generator, and is then exhausted by a fan through a ventilating shaft through the roof, or to the different parts of the power house as desired. Because of the large volume of air required (about 120,000 cu. ft. per minute) it was necessary to give special consideration to the ventilation in the construction of the generator and power house. The unique provisions in the design of the power house for the generator ventilation are described in another paper being presented at this meeting.

Flywheel Effect

To meet the requirements of the hydraulic equipment in regard to speed regulation under conditions of sudden changes in load, the rotor was required to have a much larger flywheel effect than would have

Fig. 4—Stator Coil

been obtained if the rotor were designed with reference only to the strength required. A limited amount of this flywheel effect was available in the pole pieces with their coils, and the balance had to be obtained principally in the rim of the rotor spider. It was found that if the axial length of the rotor spider rim were limited to the length of the pole pieces the radial thickness of the rim would be so great that the air passages between the rim and the hub would be re-

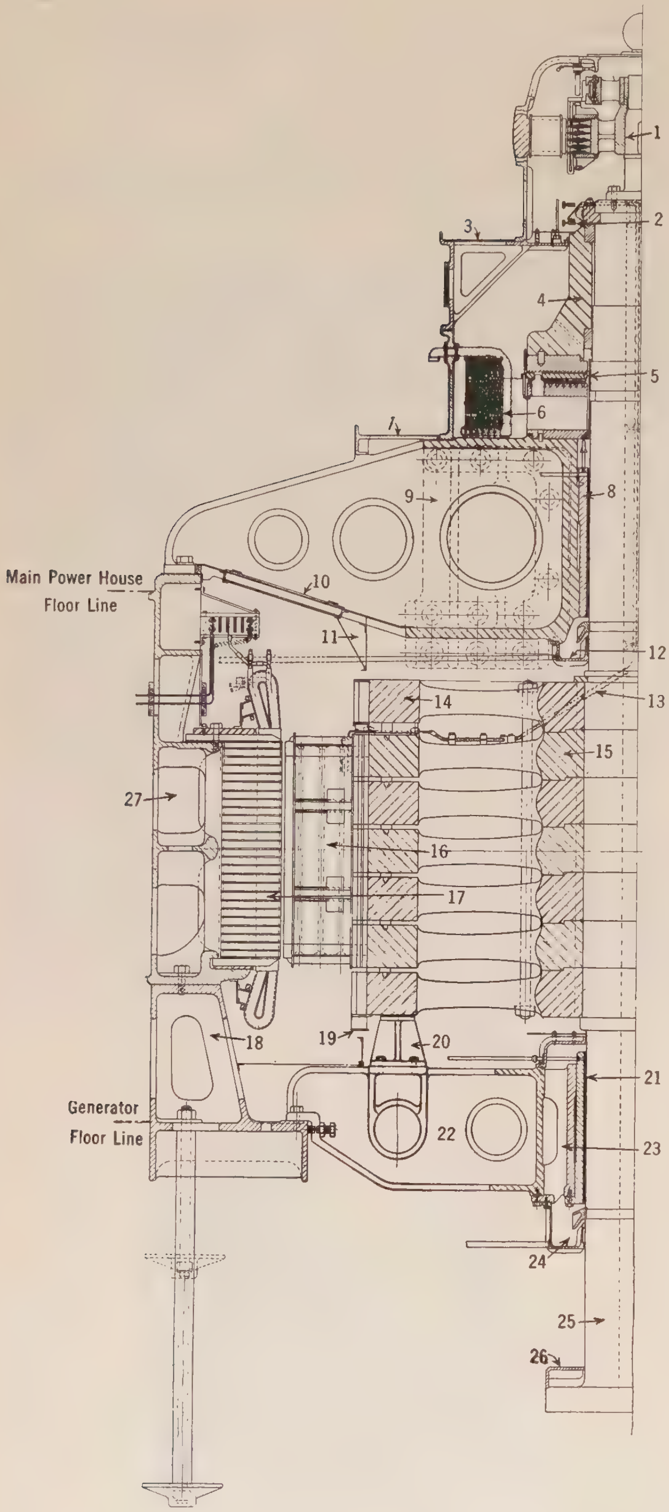

Fig. 5—Complete Assembly Section of Unit

1. Exciter.
2. Collector rings.
3. Exciter platform.
4. Thrust collar.
5. Spring thrust bearing.
6. Water cooling coils.
7. Thrust bearing platform.
8. Upper guide bearing.
9. Upper bearing bracket.
10. Cover plate and manhole.
11. Air baffle ring.
12. Upper oil drip pan.
13. Collector leads.
14. Flywheel section.
15. Rotor spider section.
16. Pole piece.
17. Stator core.
18. Base ring.
19. Fans.
20. Pedestal for supporting rotor.
21. Lower guide bearing.
22. Lower bearing bracket.
23. Lower guide bearing housing.
24. Lower oil drip pan.
25. Shaft.
26. Coupling bolt guard.
27. Stator frame.

stricted too much to allow sufficient air to reach the upper ends of the rotor and stator coils. Therefore the unusual arrangement was adopted of providing two independent spiders or flywheels mounted on the shaft, one at each end of the rotor spider proper. These flywheels are of the same diameter as the rotor spider in order to allow for the assembly of the pole pieces. The rotor spider is sectionalized into five wheels so that the complete rotor with the flywheels consists of seven separate wheels which are mounted on the shaft, one above the other. The hubs of these wheels are slightly wider than the rims so that openings are left between the rims to allow air to pass through to the spaces between the pole pieces. The ventilation is further assisted by curved fan blades attached to each end of the rotor and the recirculation of the air is prevented by baffle plates and covers around the ends of the stator windings.

Fig. 6—Upper Guide Bearing

Field Coils

The field coils are probably the largest ever made. Each coil is wound from a continuous strip of copper 1100 feet in length and weighing 2600 pounds. This strip is wound on edge in the usual manner and the adjacent turns are insulated from each other with asbestos and mica. The insulation between the coil and the pole core is of mica sheets while the insulating collars are of asbestos board so that the coils can be subjected to considerable heat without injury. This fire-proof insulation was not thought necessary because of an excessive temperature rise in normal service, but to prevent injury to the coils by a fire in the generator resulting from a failure in the stator winding.

Poles

The pole pieces are of the usual construction having $\frac{1}{8}$-inch punchings riveted together between heavy cast steel end plates. Each pole has three parallel *T*-shaped dovetails which are designed to withstand the stresses due to double normal speed, without exceeding half the elastic limit of the material. Each pole with its coil weighs five tons and the peripheral velocity

of the pole face at normal speed is over two miles per minute. The flywheel effect of the complete rotor is equivalent to 21,000,000 pounds at one foot radius. The shaft which is 30 inches in diameter in the bearings, has a solid forged coupling. In order to insure ample stiffness of the shaft, the critical speed with the rotor and shaft in a horizontal position was kept well above the run-way speed of the water-wheel. The upper end of the shaft has a groove machined in it to receive a split ring for transmitting the weight of the rotating parts to the thrust collar and spring thrust bearing.

Bearings

The guide bearings are of the usual General Electric construction for this type of large generator. They are provided with a number of small grooves for lubricating purposes.

The thrust bearing is of the spring supported type and is designed to carry a total load of 500 tons. Briefly, the distinctive feature of this type of bearing is that the stationary part consists of a relatively thin steel plate with a babbitted bearing surface which is supported by a large number of coil springs. The slight flexibility of the plate in conjunction with the spring support permits the plate to conform with any slight irregularity either in the supporting structure or the shaft and thrust collar without causing local unit pressures large enough to prevent the maintenance of a film of oil between the bearing surfaces. The thrust bearing operates in a bath of oil which is renewed at a comparatively low rate with clean oil from the station oil system. The heat generated in the bearing is taken up directly by the oil as it passes through and around the bearing plates and is then removed from the oil by water cooling coils immersed in the oil bath.

Bearing Brackets

The upper bearing bracket or bridge-tree for supporting the thrust bearing and exciter, has eight arms and is of cast steel. Because of shipping limitations it is split into halves which are joined together with fitted bolts. The complete bracket was tested at the factory with a load of 1000 tons by means of hydraulic jacks. This test load is double the normal operating load and gave assurance that the castings were sound. Cast steel was used for these brackets not only because of its greater strength but also to limit the deflection to a value that would not interfere with the adjustment of the bearings or other parts of the generator and turbine. The calculated deflection of 47 mils was reasonably consistent with the observed value of 35 mils. The castings were slightly thicker than the drawing dimensions which fact probably accounts for the difference between the two values.

The openings between the arms are closed with sheet steel covers. Manholes of generous dimensions in these covers permit ready access to the upper part of the rotor and stator for cleaning and inspection.

In view of the fact that this power development is public enterprise and therefore will be open to public inspection, much attention has been paid to the design of the thrust bearing bracket, exciter and platforms, and railing, to obtain graceful proportions, and at the same time present an impression of strength and massiveness in keeping with the great power capacity of the generator and station. Two platforms are provided the lower one for inspection of the thrust bearing and the upper one for the inspection of the exciter and collector rings. The exciter armature is mounted on a short shaft with a forged coupling which is bolted to the top of the generator shaft. The collector rings are mounted on the generator shaft just below the exciter coupling and in case the exciter armature is removed for repairs it is not necessary to disturb the generator collector rings and the generator can be kept in service while the exciter armature is being repaired.

The lower guide bearing bracket is supported on the inner projection of the base ring. The opening for the guide bearing is large enough to pass the coupling on the shaft. The guide bearing shell is made as light as is consistent with good construction to facilitate removal, and is supported in the bearing bracket by the housing. Both the shell and housing are assembled and removed from below the bracket. The arms of this bracket have pads directly beneath the rim of the rotor spider, four of which are for the air brakes. The other four are to be used for lifting jacks for raising and supporting the rotor when assembling and dismantling the thrust bearing. The arms are designed so that four of them have ample strength to support the weight of the rotating parts of the generator and waterwheel.

Dimensions and Weights

In conclusion the following weights and dimensions may assist in formulating a conception of the size and proportions of these generators:

Outside diameter of stator frame........	24 ft. 6 in.
Over-all height from face of coupling to top of exciter..........................	33 ft. 10 in.
Over-all height from base ring..........	28 ft. 3 in.
Weight of stator with core and windings..	175 tons
" " base ring.....................	37 "
Diameter of shaft in rotor..............	32 inches
" " coupling..................	53 "
Length of shaft.......................	30 feet
Weight of shaft.......................	40 tons
Weight of upper bearing bracket........	50 "
" " lower " "	12 "
Diameter of thrust bearing.............	69 inches
Load on thrust bearing.................	500 tons
Weight of one pole piece with coil.......	5 "
" " rotor spider (7 sections).......	190 "
Total weight of rotor..................	310 "
" " " generator with exciter....	625 "

65 miles of wire used in one set of stator coils.

450 miles of tape used to insulate one set of stator coils.

110,000 punchings required for stator core.

3½ miles of copper strip used for one set of pole coils.

4 tons of cooling air required per minute.

Determination of Temperature of Electrical Apparatus and Cables in Service

BY E. J. RUTAN

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Test Dept. New York Edison Company

Temperature measurements constitute a large part of the work of the test department of an electric light and power company in the acceptance and maintenance of the electrical equipment. The methods of measuring temperature which are applicable to this work are discussed in this article. The characteristics of the different kinds of temperature measuring apparatus are brought out by describing a number of actual tests.

In the article considerable attention has been given to various forms of thermocouples which have been found very useful in obtaining temperature measurements on cables and in underground conduit systems.

THE following paper is intended as a discussion of the various commonly used methods of determining temperature, such as would be employed in the test department of an electric light and power company. The temperature measurements, as a matter of fact, constitute a large part of the acceptance tests of electrical equipment and supplies, and form a considerable part of the investigation of service performance and characteristics after the equipment has been accepted and placed in service.

The four commonly used means of measuring temperature are by thermometer, by resistance thermometer, by thermocouple and by change in resistance in the winding or circuits of the apparatus under test.

If an electric light and power company rigorously maintains the policy of testing for acceptance, as far as possible, equipment and materials purchased, it results in the presentation of many varied kinds of equipment and material with consequent problems in connection with their test. This paper proposes to discuss the adaptation or application of the various methods of measuring temperature to specific kinds of equipment and material, rather than to discuss the various methods in a general way. It is understood that the temperature measuring devices themselves are well established and are not presented here as novel and probably not new in their application. However, many test details arise in connection with the use or application of the various forms of measurement to the particular equipment under test. The discussion of a number of specific test conditions will bring out some of the characteristics and limitations of the various methods of measuring temperature.

The work of a test department of this character covers a fairly broad field, but it does not require the use of every type of temperature measuring apparatus, nor are all types suited for the conditions encountered. In general, the temperatures which are measured are less than 200 deg. cent. and in most cases are confined within the limits permissible in electrical apparatus. The measurements usually need not be made more precisely than to the nearest degree centigrade. Accordingly, the discussion which follows will pertain to measurements in this temperature range and of this general precision.

Before describing the detailed applications, some of the types and characteristics of the four kinds of temperature measuring apparatus will be briefly discussed.

The thermometer method is the simplest and most convenient to use. With the thermometer the indication of temperature is obtained directly without the use of any auxiliary equipment.

The following forms of thermometers are found to supply the general demands of test work.

1. Indicating (mercury and spirit).
2. Recording.
3. Maximum and minimum indicating (constricted-bore type and Six's type).

The mercury indicating thermometers of the gas filled type are to be preferred for most work. These thermometers are calibrated for partial immersion (frequently 3 inches). This is desirable as in ordinary use only the bulb is in contact with the apparatus. The spirit thermometers are calibrated for full immersion and are used in locations where air or fluid temperatures are desired and danger from high voltage makes it inexpedient to use mercury thermometers. In case of breakage of spirit thermometers, the hazard from voltage breakdown in high tension apparatus is less than with mercury thermometers, due to the quick evaporation of the fluid.

The recording thermometers are standard instruments which can be purchased in various types and ranges. It is found that the self-contained instrument suited for ambient air temperature measurements has the widest application for portable use.

Where apparatus is inaccessible or where there is hazard from high voltage, it is frequently not practicable to use thermometers. In such cases, the resistance thermometer or thermocouple properly insulated or the change in resistance method are used.

The shape and bulk of the resistance thermometer units do not always make them readily applicable to test conditions. In order to obtain sufficient strength, the unit must be made large, the small units being fragile and expensive. This type of apparatus has

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been found better suited for permanent installation rather than for portable testing work.

In general test work, the thermocouple has proved more useful than the resistance thermometer. It is small, strong, easily made up, and will give readings at a distance with a sufficient degree of accuracy. A copper constantan couple is used for temperatures up to 200 deg. cent. The indication is obtained by means of a potentiometer type temperature indicator calibrated directly in degrees for this type of couple. This is a null method of measurement which avoids correction for lengths of connecting leads and permits accurate determination of temperatures at considerable distance from the instrument.

The thermocouple wire for use with these instruments can be purchased with a guarantee that the results will be correct within one degree centigrade over the entire scale. This is sufficiently accurate for the work encountered, and presupposes that the constantan wire has been carefully selected. The two conductors are made up in a duplex wire and each insulated with rubber. Surrounding both wires there is a weatherproof covering. Rubber insulation should cover each wire separately as cotton insulation alone is liable to absorb moisture and produce internal galvanic action introducing errors in the temperature readings.

It has been found desirable to give each shipment of thermocouple wire on receipt acceptance tests to insure that its characteristics are as guaranteed and to insure against defective insulation.

1. Each coil of wire is tested as a thermocouple between 20 deg. cent. and 150 deg. cent. with the portable direct reading potentiometer temperature indicators, in order to ascertain that its e. m. f. agrees with the standard curve.

2. The insulation resistance between the two conductors of each coil is measured with a 1000-volt megger.

3. A 50-foot sample is cut from the coil and its insulation resistance is measured as in (2).

4. The sample in (3) is heated to 100 deg. cent. for one hour and then connected to a temperature indicator with the end open circuited in order to determine whether any electrochemical e. m. f. is generated.

5. The insulation resistance of the sample is measured while hot, following the same precedure as in (3).

After passing these tests, the wire is ready for use. Couples can be made up in the field by simply twisting the copper and constantan together and soldering the junction. The length can be made to suit the field conditions, and no further calibration is needed.

The fourth method of measuring temperatures makes use of the change in resistance of the windings. The results obtained by this method are accepted as the average temperature of the conductors. It is not possible to measure hot spot temperatures by this method. In tests on transformers, regulators, reactors and cables, the resistance method is extensively used.

With the above methods available, the selection of the method depends on the character and the location of the apparatus to be tested. Some of the typical tests are described below, and also the reason for selecting the various methods discussed. In describing the tests only brief mention is made of the technical details except as they affect the methods of measuring

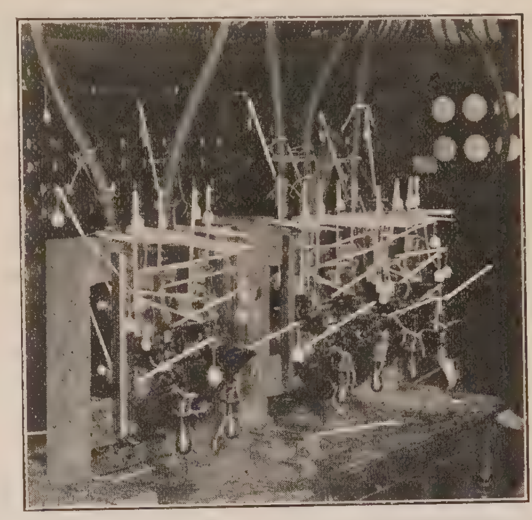

FIG. 1

temperatures. In order to give a clearer idea of the equipment under test and the temperature measuring apparatus, illustrations and diagrams of many of the tests have been included.

In Fig. 1, a group of circuit breakers is shown set up for test. The thermometer method was used because the apparatus was easily accessible and this method was the simplest. The thermometers were placed at the points where the highest temperatures were expected, at the contacts and joints. The bulbs were placed in contact with these parts and were covered with putty.

FIG. 2

On account of the small size of the breakers, the area covered by the thermometers and putty was kept to a minimum so that the radiating properties were not appreciably altered. The thickness of the putty covering was sufficient to protect the bulb from the influence of the air.

In tests where the radiating surface is very small, thermocouples have the advantage over thermometers. The arrangements for such a test are shown in Fig. 2, which is an illustration of small copper catches set up for test. The thermocouples were soldered to the catch, bus and lug. If thermometers had been used, the bulb and putty would have seriously reduced the radiating surface. The thermocouple junctions and the spot of solder did not appreciably alter the radiation, so that it was possible to make a detailed temperature survey with very little change in normal operating conditions.

In some cases, a number of methods find application. Fig. 3 is an illustration of the cable and equipment. In Fig. 4 a diagrammatic layout of the cables is given which shows the location of the thermometers and thermocouples. The cable was a three-conductor cambric-insulated high-voltage cable. Over the outer belt of insulation, there is a steel armor and over this, a weatherproof covering. The surfaces of the cables were painted so as to give different radiating effects.

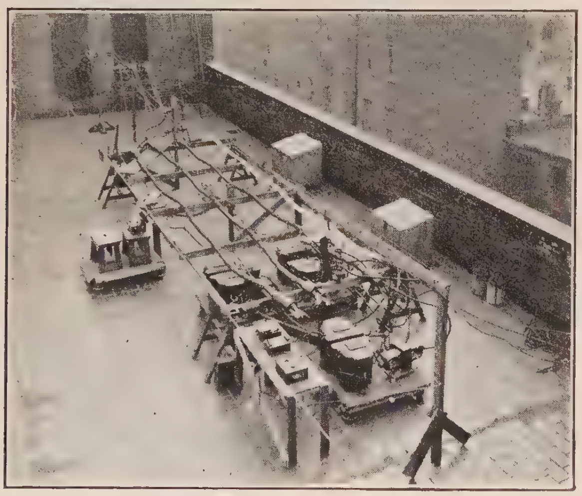

Fig. 3

The conductors of the various sections were connected together so that current from a low-voltage supply could be circulated through each of the phases. The rated potential difference was maintained by another source, so that the net dielectric losses were the same as in normal service. In arranging the circuits, provision was made so that by using a switch to throw from a-c. to d-c. supply, the conductor resistance could be measured immediately after opening the test current. The leads for the voltage measurements were permanently soldered to the conductors and brought to a central point so that the readings could be quickly taken and sources of error due to poor connections avoided. From these measurements, the average temperature of the conductors in each section was determined.

The temperature of the steel armor was measured by means of thermocouples inserted under the armor through slits in the weatherproof covering. The thermocouple wires were brought back to a dial switch shown at the center of Fig. 3. The temperature indicator was placed on an insulated platform on which the observer also sat when taking readings. This safeguard was necessary as the thermocouple leads might become alive due to a failure in the insulation.

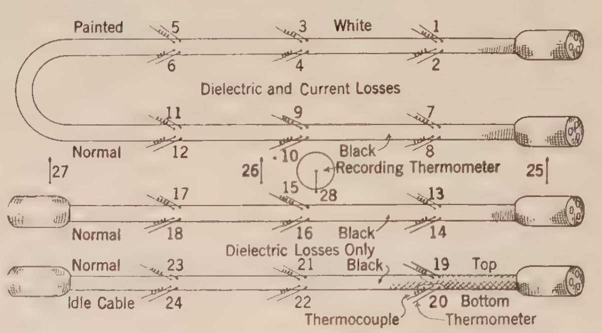

Fig. 4—Aerial Cable Test
Location of thermometers and thermocouples.

On the surface of the cables, thermometers were used to obtain the temperature. These thermometers were held down with putty. The air temperatures were measured by means of both indicating and recording thermometers.

When it is desired to obtain maximum internal temperatures, such as in a splice, the thermocouple is the best method. The location of the probable hot spots is determined and the thermocouples are located at these points.

For example, a test was made on a splice of a concentric one million-cir. mil, lead-covered cable. The problem was to analyze the temperatures in and around the splice after it was completed as it would be made up in service. The thermocouples were therefore

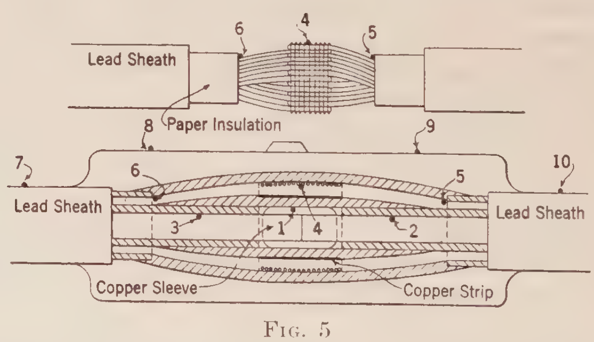

Fig. 5

built into the splice as it progressed and the normal lay of the cable insulation and lead armor was disturbed as little as possible. One thermocouple was placed at the joint in the inner conductor. This was fastened to the wiping solder used at that point. Other thermocouples were spot-soldered to the inner conductor about four inches each side of the joint, and the leads brought through a small triangular slot cut in the paper insulation, the cut being so made that the insulation could be bent back in place after the thermo-

couple was located. A cross section of the splice is shown in Fig. 5 and the location of the thermocouples on the inner and outer conductors and sheath are indicated.

The leads to the thermocouples were made as small as possible so that they could be all grouped together and brought out through a hole in the lead sleeve of the splice which was securely sealed. Fig. 6 shows an external view of the splice and the connections to the temperature indicator.

Another application of thermocouples was in tests on air-blast transformers. Thermocouples composed of flat strips were found useful for this work. These thermocouples were from one to three feet long and were made up of the copper-constantan strips encased in a micarta covering. The strips were joined to form a junction at one end and at the other the regular thermocouple wire was soldered to the strips and extended to the temperature indicator. These junctions were wedged between the low-tension winding and the separators.

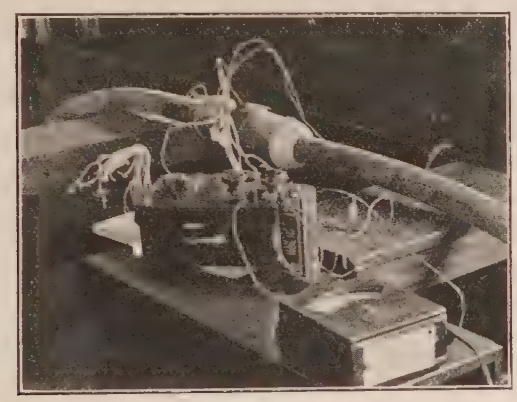

Fig. 6

Such thermocouples could not be placed in contact with the high-tension windings with safety. In order to measure the temperature of the high-tension windings, thermometers were used. These were fastened on the coils usually at the top. The readings of the thermometers were obtained through the top of the transformer by protecting the eyes with goggles, (on account of the air blast). If the thermometers were located at greater distances than two feet a galvanometer telescope was used. In addition, thermometers were lowered on strings in the air passages in order to obtain the air temperature. Spirit thermometers were used for this purpose as they were less liable to cause a ground if broken inside of the transformers.

On rotating machinery, the temperatures are obtained by thermometers when the apparatus is accessible. For example, on synchronous converters, and generators and motors, the thermometers are placed on the stationary parts such as the field coils, pole tips, frame, bearings and brush brackets and collector buses. On induction motors and other apparatus on which the major part of the windings are imbedded the resistance method gives the best results. However, thermometers are always used if possible to supplement this method.

The temperature measurements of the rotating parts are made after the machine has come to rest at which time thermometers are quickly placed on the commutator slip rings and armature windings. These readings are taken at intervals of a minute or less until the temperature has started to decrease.

On the larger higher-speed, high-voltage equipment such as turbo alternators, the temperature measurements are made by means of imbedded thermocouples or resistance thermometers usually placed by the manufacturer. The temperatures of the stationary parts, if accessible, are measured by thermometers, or thermocouples.

For investigating temperature conditions in the various parts of an underground transmission and distributing system, the thermocouple was found to be very convenient and adaptable. Tests made on cables in manholes, sheath temperature and manhole air conditions were made with thermocouple and recording thermometers. On low-tension cables, the thermocouple junctions were soldered directly to the sheath. On high-voltage cables, the junctions of the thermocouple wire were preferably soldered to small pieces of sheet copper about ½ in. by 1 in., and these securely held in contact with the sheath of the cable by means of small wooden blocks of about the same area.

The piece of sheet copper increased the contact area of the junction, thus insuring that the thermocouple junction assumed as nearly as possible the temperature of the sheath. The thermocouple junction alone produced a very small contact. Due to this relatively small volume compared to the size of its own connecting leads, the leads may conduct the heat away if they are of a lower temperature than the thermocouple in contact with the cable, which is usually the case. Such a condition would result in a lower indication of temperature than actually existed on the sheath of the cable.

The foregoing point is of general application and it has been found necessary to analyze the above effect from various angles. As a result, the junctions of the thermocouple wire were fitted in special copper slugs which have been developed by the test department of the New York Edison Company. This slug is shown in the insert in Fig. 7. This form was designed primarily for measurements of duct temperatures which by nature do not change rapidly. It is about two inches long and ⅜ of an inch in diameter, with grooves cut parallel to the axis so as to give a larger exposed area. The slug increased the exposed surface of the couple and eliminates any error which may be due to the leads conducting heat away from the couple. The increased mass of the couple made the measurements of air temperature more reliable, in that the couple did not

show temperature changes with each slight draft of air. The time lag introduced by the increased mass was less than one half hour and was considered satisfactory for duct temperature measurements. Obviously this time constant may be increased or diminished by varying the mass and relative radiating surface of the terminal.

Extensive underground temperature surveys have been made in duct banks by means of gang-cables of thermocouples, approximately 350 feet long. The entire gang-cables are built up beginning with a 3/8-in. steel-wire rope to which the thermocouples are attached. The thermocouples fitted with the above mentioned slugs are spaced every 30 feet and the pair of leads to each one brought back to one end of the cable. All the leads are bound with cord about every foot. Four layers of tape are wrapped over the entire length to protect the cable from abrasion and slight moisture.

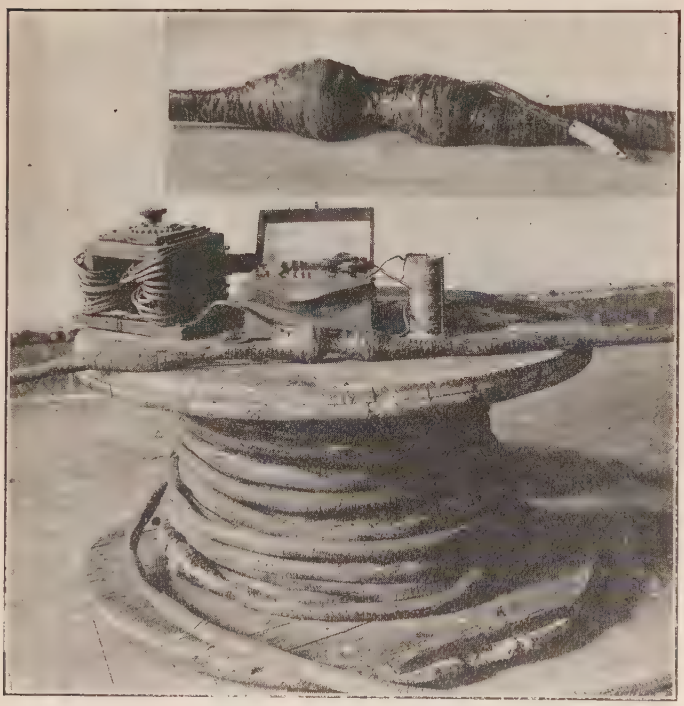

Fig. 7

In attaching these junctions on the cable, the copper slugs are heat insulated from the steel rope by means of a number of layers of tape. In order to make certain that the slugs do not come in contact with the duct walls, knobs were built up on the cable each side of the slug as shown in Fig. 6.

The complete equipment used with the cable is shown in Fig. 7. The thermocouple wires were brought back to a dial selector switch which permits any couple to be connected to the temperature indicator.

As this assembly was used throughout the year, tests were made on the dial switch and indicator when at different temperatures to determine whether the accuracy is influenced. It was found that throughout the range of temperature encountered, the precision is within one deg. cent. At extremely low temperatures, the standard cell in the indicator became unreliable. For freezing weather the standard cell was removed to a heavy heat insulated case so it could be used for long periods outdoors.

Based on the experience accumulated in using thermocouples and the gang cables, it is felt that the general accuracy of temperature measurement which should be obtained is within one degree centigrade. It will be appreciated that with a new application of temperature measuring apparatus such as the gang cable, a certain number of practical difficulties may be encountered in the field. This has been the case in this instance and several sources of error have been encountered and eliminated which are recorded here for the benefit of others who may desire to attempt similar investigations:

1. Thermocouple wire made by a reputable manufacturer was used at first which had unimpregnated cotton insulation between the conductors. It was found that this wire readily absorbed moisture of various and unknown chemical characteristics, which produced galvanic effects and caused errors in the temperature readings. Immediately this condition was understood, it was corrected by using rubber insulation around each individual conductor, and also around the pair of conductors comprising the thermocouple.

2. After the gang cables had been in service for a considerable period, it was found that breakages occurred in the copper conductor near the copper slug terminal. Relatively few breakages occurred in the constantan wire. These breakages were due to the wear and tear in service incidental to pulling the cable in and out of ducts. It was exceedingly difficult to detect the breakage of the wire since mud and moisture from the duct entered the cable and produced galvanic action between the conductors at the break near the slug terminal. This error has been eliminated by substituting a stranded copper conductor for the solid copper conductor. Additional protection has been obtained by water-proofing the junction between the thermocouple insulation and the copper slug terminal to exclude moisture from the thermocouple wire.

3. It was found that the insulation ordinarily furnished with the thermocouple wire did not satisfactorily resist service usage. Accordingly, thermocouple wire was obtained insulated with especially durable insulation capable of standing considerably more wear and tear than the ordinary rubber insulation previously furnished.

This thermocouple gang-cable has been found very useful in plotting the temperatures along a duct bank. For analyzing temperatures which might emanate internally in the cables lying in the bank or externally from steam pipes and other sources of heat outside the bank. This gang cable is of such size that it can be

used only where an empty duct is available in the bank, as it cannot be pulled through a duct already occupied by a cable.

In the morning the cable was pulled into an empty duct of a bank so that the first thermocouple extended into the next manhole. The manholes were closed and readings taken over the peak load period, after which time the cable was removed.

As a check on the accuracy of the thermocouple indications, and in order to prevent any discrepancies from entering, a thermometer was placed in contact with the terminal of the first thermocouple in the far manhole. Simultaneous readings were taken on the thermometer and thermocouple just before removal.

The life of a cable of this character in nearly continuous testing service at numerous locations is about three months.

In cases where the space was limited, or it was inconvenient to bring out thermocouple leads, the maximum indicating thermometer was used. There are the two types, namely the Six's maximum and minimum indicating and the restricted bore mercury thermometer which is only maximum indicating. These were placed in junction boxes in the middle of streets, where, due to traffic, thermocouples could not be used and where on account of the restricted space, it was impossible to set recording thermometers. The results obtained by these thermometers gave only the range of temperature during a load cycle.

The data and methods given above are intended to set forth some of the procedure being used to measure temperatures in the general testing work of a large public utility. They are advanced with the belief that they will be of value to engineers engaged in similar work and will bring out discussions of other methods for achieving the necessary test results.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

ULTRA-VIOLET LIGHT

An article in the May, 1922, *General Electric Review* by Llora C. Krueger entitled, "Ultra-Violet Light, Its Uses and Possibilities," briefly outlines the early history of ultra-violet light. Modern theories treat radiation as a propagation of energy in the form of waves which have been shown to vary continuously in length from twenty to thirty thousand meters, in the wireless region, to the extremely short disturbances involved in X-rays. The visible spectrum covers only a very short range of these waves, extending from 7600 to 3900 Angstrom units. Ultra-violet light is produced in many ways, but few of them are sources of much energy. All artificial light contains more or less ultra-violet radiation and the sun emits a continuous spectrum of great intensity, but wave lengths shorter than 2950 Angstroms are absorbed by the atmosphere to such an extent that very little ultra-violet light reaches the surface of the earth.

Limelight, burning magnesium ribbon, incandescent lamps, arcs between metals, spark-gaps and vacuum tubes are sources of ultra-violet light but the mercury arc in a quartz tube and the magnetite arc are the best commercial sources. The flaming arc has great possibilities owing to the various substances which can be incorporated in the electrodes. Ultra-violet light is a great accelerator of chemical reactions and readily effects the decomposition of alcohols aldehydes, organic acids and ketones. Under the action of ultra-violet rays, the velocity of reaction is proportional to the intensity of the light, but is independent of the concentration of the reacting substances. The action of the rays appears to be catalytic. Ultra-violet light has a strong action in causing fluorescence and phosphorescence, certain wave-lengths being much more effective than others. When polished metals are exposed to ultra-violet light negative electrons are given off and the metal becomes positively charged, if insulated, and discharged, if already negatively charged. This phenomenon is made use of in the photo-electric cell. Certain wave-lengths of ultra-violet rays were used in a clever signaling device, during our recent war, by Dr. Louis Bell, the rays used being invisible except through field glasses fitted up to receive them.

Ultra-violet rays are used for testing the fading qualities of dyes toward sunlight.

Much research work has been carried out to test the abiotic properties of ultra-violet light. It can be used most effectively in treating various skin diseases and transparent liquids can be sterilized by ultra-violet light acting through thin layers. Young cultures of bacteria are less resistance to these rays than older ones.

The numerous experiments carried out to determine wherein the destructive action of ultra-violet light lies seem to indicate that the deadly action is due to some quality inherent in the rays themselves, and not to the action of some poisonous substance formed by them. Apparently the radiation kills living cells by changing the protoplasm of the cells in such a way that certain salts can combine with the protein of the protoplasm to form an insoluble compound.

Numerous interesting experiments are being tried on the action of ultra-violet light on the development of eggs. The protoplasm seems to be altered chemically by the ultra-violet light so that it cannot take part in the normal development of the organism. Henri has shown that there is a minimum value of intensity of irradiation for minute animals below which they do not respond to the action of the rays regardless of the duration of irradiation.

Hasselbalch and Russ have tried interesting experi-

ments on the absorptive power of the skin, which was found to be very absorbent for rays of wave-length between 3000 and 2100 Angstroms. Apparently not more than one part in a thousand of this radiation penetrates to a depth of half a millimeter in the skin. With rays of wave-length 3000-3800 Angstroms, it is a question whether as much as 1 per cent of the radiation penetrates as deep as one millimeter.

Ultra-violet light is used to test the wearing qualities of fabrics which are to be exposed to the weather, for instance, in aeroplane wings. It is also used in testing jewels since gems exhibit fluorescence in different ways depending on their origin. For purifying water supplies the rays very successful. In the province of pathology, the field of usefulness of ultra-violet rays is being constantly enlarged.

Schumann was the pioneer worker in the spectroscopy of ultra-violet rays. Lyman and Millikan have extended his work with even greater precision and nicety until now there is apparently no gap between the known spectral lines for certain of the metals in the extreme ultra-violet region and the lines from soft X-rays. The spectral lines from hard X-rays overlap those of the soft gamma rays so that we have a spectrum of accurately determined wave-lengths from the wireless region to the gamma rays from radium. All these phenomena, though so different in their manifestations, whether as wireless waves, visible light, or X-rays are considered now as fundamentally of the same origin and are the result of the motion of the units of negative electricity, the electrons. As our knowledge of the extreme ultra-violet region of the spectrum increases, its importance in helping us toward a more complete understanding of the structure of the atom and the nature of radiation becomes evident.

A resume of the literature since Behren's bibliography published in 1914 is appended to the article in the *G. E. Review*.

MODERN PRACTISE IN STREET LIGHTING

In the paper presented by Earl A. Anderson at the Twenty-Seventh Annual Convention of the American Society for Municipal Improvements held in Baltimore, Md., some months ago, the types of street lighting systems most favored at the present time for lighting the different sections in cities were described. An abstract of the information contained in this paper is given in the following paragraphs which show in effect, therefore, modern street lighting practise in this country.

For important business streets in cities, the most widely favored method of lighting consists in the use of single-light ornamental standards mounted at heights from 14 to 18 feet and spaced opposite each other at distances of 80 to 120 feet. For very narrow streets the lamps may be placed on one side only or staggered at the same spacing. An important increase in efficiency is secured by the use of lamps of 600, 1000, 1500 or 2500 candle power instead of the three, four or five-light clusters using small lamps which were the vogue before the introduction of the high-powered gas-filled incandescent lamp. There is at present a very noticeable tendency to depart from the use of the opal ball or globe, and to use instead a lantern structure, which by many is considered more pleasing in appearance.

Instead of the single-lamp standards spaced relatively close together, some cities have adopted standards carrying two or even three high-power lamps mounted 20 to 30 feet above the street and spaced 150 to 200 feet apart. The resultant effective illumination is not greatly different from the more usual arrangement and the exceptionally high mountings minimize any possibility of glare from the lamps. On the other hand, there appears to be much weight on the side of those who contend that on business streets the surrounding brightness of buildings, show windows, etc., is such that there is no possibility of serious glare even with the large lamp at the lower mounting of 15 to 18 feet and that the desirable "white way" effect is enhanced by lanterns at these heights spaced 80 to 90 feet apart.

The demand for higher levels of illumination on business streets has led in some cities to the consideration of lamp standards carrying two or three 1000 or 1500 candle power lamps each and spaced no more widely apart than previous single-lamp installations. It is quite possible that there will be an increased development of this tendency, especially in the larger cities where the crowds from evening business and amusements have become such that in many cities "white way" systems, which were installed quite largely as an ornamental or advertising feature, are even now barely adequate from the standpoint of lighting safety.

A satisfactory provision for thoroughfares outside the business district is an arrangement of lamps of 600, 1000, or 1500 candle power spaced from 150 to 250 feet apart, or at a maximum 300 feet. If the street is very wide it may be necessary to consider each side as a separate street and provide lighting accordingly. The mounting height should be 20 or preferably 25 feet in order to remove the bright light sources farther from the line of vision, and also in order to obtain a better spread of illumination. In the past, especially where there were wooden pole lines on the streets, it has been common practise to use a lighting fixture suspended from a mast arm. The mast arm has the virtue of bringing the lamp out over the street surface, thereby causing the light rays to clear low hanging foliage of adjacent trees. Bringing the lamp over the pavement also increases the possibilities of seeing objects by silhouette against the bright spot of light beneath the lamp or against the bright streak or glint reflections from the pavement.

JOURNAL
OF THE
American Institute of Electrical Engineers

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WILLIAM MCCLELLAN, *President*
GEORGE A. HAMILTON, *Treasurer* F. L. HUTCHINSON, *Secretary*

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month

A. I. E. E. 38th Annual Convention
NIAGARA FALLS, ONTARIO

THE Annual Convention at Niagara Falls this year gives promise of being an outstanding success among the many notable conventions of the Institute. Centrally located between the East and Middle West, and served with ample transportation facilities, it is easily accessible to a large body of the membership both in the United States and in Canada. The location is also one of interest to all Americans and Canadians, being one of the famous scenic resorts of the world, but it holds a particular lure for the electrical engineer on account of the wonderful object lesson in the utilization of water power which it presents. An opportunity to visit and inspect the vast industrial developments which are operated by the power of Niagara Falls should prove an inspiration to every member of the electrical engineering profession to which these developments owe their inception.

Aside from its advantageous location, the convention will present this year an unusually full program of technical papers as well as a varied and interesting schedule of inspection and pleasure trips, sports, games and other entertainment features, which cannot fail to appeal to the interest of all who attend the convention. Special provision has been made for the entertainment of visiting ladies.

While various Institute activities and excursions have been planned to cover the entire week of June 26-July 1, the official convention days are Tuesday to Friday, June 27-30, inclusive. Monday has been set aside for Conferences, under the auspices of the Sections Committee, of Institute officers and Sections Delegates, and all members of the Institute who desire to attend will be welcomed at these conferences. For Saturday, July 1, a visit to Toronto has been arranged, details of which will be announced during the convention.

TENTATIVE PROGRAM
Monday June 26

Meetings under the auspices of the Sections Committee.

Tuesday Morning June 27

GENERAL SESSION—10:00 A. M.

The convention will assemble for address of welcome, general announcements, etc., after which the meeting will separate into two parallel sessions as follows:

SESSION I—10:30 A. M.

1. *The Two-Stage Current Transformer*, by H. B. Brooks, Physicist, Bureau of Standards, Washington, D. C., and F. C. Holtz, Chief Engineer, Sangamo Electric Co.
2. *Three Thousand Tests on the Dielectric Strength of Liquid Insulation*, by J. L. R. Hayden and W. N. Eddy, both of General Electric Co.
3. *Control of Gaseous Conduction*, by V. Bush and C. G. Smith, both of Research Department, American Radio and Research Corporation.
4. *Determination of Temperature of Electrical Apparatus and Cables in Service*, by E. J. Rutan, Test Department, New York Edison Co.

SECTION II—10:30 A. M.

5. *The Economics of Direct-Current Railway Distribution* (with particular reference to the *Automatic Substation*), by L. P. Crecelius and V. B. Phillips, both of Crecelius & Phillips, Cleveland, Ohio.

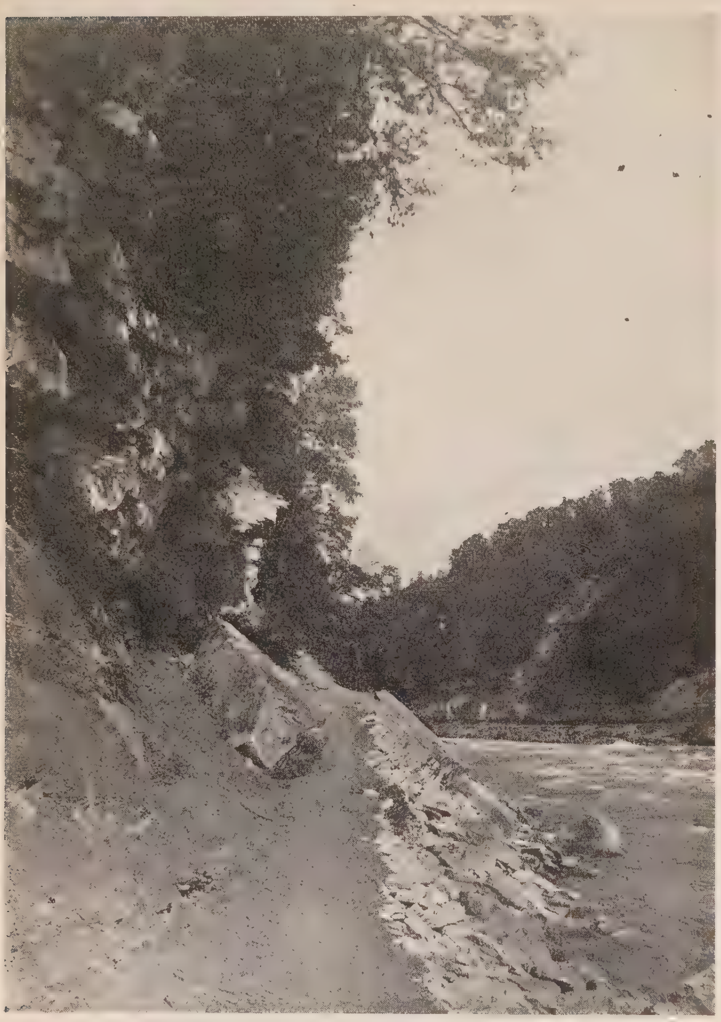
HORSESHOE FALLS FROM CANADIAN SIDE

6. *Light Without Glare*, by Ward Harrison, Engineer, National Lamp Works, Cleveland, Ohio.
7. *Philadelphia-Pittsburgh Section of the New York-Chicago Cable*, by James J. Pilliod, American Telephone and Telegraph Company, New York.
8. *A Method of Determining Resultant Input from Individual Duty Cycles and of Determining Temperature Rating*, by Bassett Jones, Consulting Engineer, New York.

Tuesday Afternoon—2 P. M.

Four papers will be presented in relation to the Queenston hydroelectric plant, as follows:

9. *Queenston-Chippawa Development of the Hydro-Electric Power Commission of Ontario*, by F. A. Gaby, Chief Engineer, Hydro-Electric Power Commission of Ontario.
10. *Description of the 45,000-kv-a. Queenston Generators*, by B. L. Barns and F. Bowness, both of Canadian General Electric Co., Ltd.



River Path, Niagara Glen

11. *Design of 45,000-kv-a. Generators, Queenston Plant*, by R. A. McCarty, Engineering Department, Westinghouse Electric & Manufacturing Co., and H. U. Hart, General Manager, Canadian Westinghouse Company.
12. *Features of Main Power House Transformers for Queenston Plant*, by C. A. Price, Assistant Chief Engineer, Canadian Westinghouse, and M. E. Skinner, Assistant to General Manager, Duquesne Light Company.

Golf, qualifying round.

Tuesday Evening—8 P. M.

President's Address.
Reception.
Informal Dance.

Wednesday Morning, June 28—10 A. M.

13. *Questions Relating to Standards of Rating*, by F. D. Newbury, Power Engineering Department, Westinghouse Electric & Manufacturing Co.
14. *Probable Values of Conventional Allowance for A-C. Generators Stator Windings*, by F. D. Newbury.
15. *Temperature Limits in Large Machines*, by P. Torchio, Chief Electrical Engineer, New York Edison Co.
16. *Higher Steam Pressures or Pulverized Coal?* by F. A. Scheffler, Manager, Power Department, Fuller Engineering Co.

Wednesday Afternoon—2 P. M.

Visit to the Queenston Development of the Hydro-Electric Power Commission of Ontario.

Wednesday Evening—8 P. M.

Lecture on popular subject.

Lecture on *Niagara Falls Plants*, by J. L. Harper, suggesting the most important features of these plants to be seen by visitors on inspection trips.

Informal Dance.

Thursday Morning, June 29—10 A. M.

A group of seven papers will be presented relating to cable insulation.

17. *Rating of Cables in Relation to Voltage—Summarized History*, by the Subcommittee on Wires and Cables of the Standards Committee.
18. *Dielectric Losses and Stresses in Relation to Cable Failures*, by D. W. Roper, Superintendent of Street Department, Commonwealth Edison Co.
19. *On the Minimum Stress Theory of Cable Breakdowns*, by D. M. Simons, Standard Underground Cable Co.
20. *Effect of the Composite Structure of Impregnated Paper Insulation on Its Electric Properties*, by W. A. Del Mar and C. F. Hanson, both of the Habirshaw Electric Cable Co.
21. *Potential Gradient in Cables*, by W. I. Middleton and E. W. Davis, of the Simplex Wire and Cable Company, and Chester L. Dawes, Assistant Professor Electrical Engineering of Harvard.
22. *Corona in Air Spaces in a Dielectric*, by J. E. Shrader, Research Physicist, Westinghouse Electric & Manufacturing Co.

Looking From Hotel Clifton, Niagara Falls, Ont., A. I. E. E. Convention Headquarters

23. *Action and Effect of Moisture in a Dielectric Field*, by Delafield Du Bois, Research Engineer, Safety Insulated Wire and Cable Company.
24. *Rating of Cables in Relation to Voltage—Bibliography on Dielectrics*, by D. M. Simons, Standard Underground Cable Co., Pittsburgh, Pa.

Thursday Afternoon

Board of Directors' Meeting.
Inspection Trips. (See "Plant Inspections" below)
Ladies' Bridge Party
Music Recital, by Prof. V. Karapetoff

Thursday Evening—8 P. M.

Symposium on Engineering Education.

25. *Some Suggestions for Possible Improvements in Methods of Engineering Education*, by B. G. Lamme, Chief Engineer, Westinghouse Electric & Manufacturing Co.
26. *Education*, by S. E. Doane, Chief Engineer, National Lamp Works of General Electric Co.
27. *Principles of Engineering Education*, by P. Torchio, Chief Electrical Engineer, New York Edison Co.
28. *Better Preparation of Students for Railway Work*, by I. C. Forshee, Electrical Engineer, Pennsylvania Railroad.
29. *Training for Character*, by A. M. Dudley, Manager, Automotive Engineering Department, Westinghouse Electric & Manufacturing Co.
30. *Some Suggestions Concerning the College Education of an Engineer*, by Carl Hering, Consulting Electrical Engineer, Philadelphia, Pa.

Friday Morning, June 30—10 A. M.

31. *Baltimore Oil Circuit Breaker Tests*, by H. C. Louis, Chief of Tests, Consolidated Gas, Electric Light & Power Co., Baltimore, Md., and A. F. Bang, Testing Engineer, Pennsylvania Water & Power Co.
32. *Tests on General Electric Oil Circuit Breakers at Baltimore*, by J. D. Hilliard, Engineer, General Electric Co.
33. *Tests on Westinghouse Oil Circuit Breakers at Baltimore*, by J. B. MacNeill, Engineer, Westinghouse Electric & Manufacturing Co.
34. *Transmission Line Relay Protection—II*, by E. A. Hester, Brooklyn Edison Company, R. N. Conwell, Public Service Corporation, New Jersey, O. C. Traver, General Electric Co., Schenectady, N. Y., and L. N. Crichton, Westinghouse Electrical and Manufacturing Company, all of Relay Subcommittee of Protective Devices Committee.

Friday Afternoon—2 P. M.

Golf Finals
Tennis Finals
Ball Game
Afternoon Tea, Country Club.

Post-Convention Excursions

Visit to Toronto—Details to be announced at the Convention.

Visits to Summer Resorts near Niagara—See announcement below.

ENTERTAINMENT

Athletic Events

Golf—Arrangements have been made for a golf tournament in three flights at the Niagara Falls Country Club. The first flight will compete for the Mershon Cup. The Country Club has a high-grade eighteen-hole course and a very attractive club house. Golf enthusiasts will be assured of a most delightful experience at their favorite pastime.

Tennis—A tennis tournament will be conducted on the courts of the Niagara Falls Tennis Club, which is situated quite close to the Clifton Hotel. There will be competition to suit all tastes and under most pleasant conditions.

Baseball Game—According to custom a baseball game will be staged at the latter end of the Convention. The scene of the encounter will be in Victoria Park, handy to Convention Headquarters and amid beautiful surroundings.

Ladies' Entertainment

Gorge Route Trip—This trip will be held in the morning and will prove most pleasurable to all those who have not previously viewed the Cataract in this way, and scarcely less so to those who have.

Auto Trip—Another morning will be devoted to an auto trip through the surrounding country. The Niagara Peninsula is famous for its orchards and vineyards. Though blossom time will be past, this beautiful countryside will still present much to please the eye.

Bridge Tournament—A bridge tournament is being arranged for the ladies to occupy one of the spare periods.

Afternoon Tea at Country Club—An afternoon tea will be given for the ladies at the Country Club on the last day, to fit in with the final athletic events and presentation of prizes.

Dancing—The usual informal dance will follow the President's Reception. Provision will also be made for dancing on one or more other evenings.

Golf for Ladies—Arrangements will be made at the Country Club for those ladies who wish to play golf. If a sufficient number are interested a competition will be arranged for them.

Musical Recital

Professor Karapetoff has kindly consented to treat the music lovers as he has on so many previous occasions. He proposes to introduce for the first time in public a new five-string cello, which he has developed himself. This is an event of unusual significance.

Special Lecture

On an evening early in the Convention Mr. J. L. Harper, Chief Engineer of the Niagara Falls Power Company, will give a lecture covering historically the development of power at Niagara and its various power plants. It is expected that this lecture will greatly enhance the enjoyment to be derived from visits to the plant.

Plant Inspections

An afternoon will be specially set aside for an inspection of the *Queenston Power Plant.* Arrangements will also be made whereby this plant can be seen on other days by those desiring more detailed information. Similar arrangements will also be made for visits by individuals or groups to any of the other power plants on any day of the Convention, within designated hours.

Detailed information will be available regarding all such visits at the registration booth.

Toronto Entertainment

The Toronto Section desires to have as many as possible of those attending the Convention visit Toronto on Saturday, July 1st. Entertainment will be provided. Full details of this invitation will be announced at the Convention.

Post-Convention Trips

Many popular Canadian summer resorts, such as Muskoka Lakes, Georgian Bay, Thousand Islands, and the Saguenay, are within easy reach of Niagara Falls, via Toronto. Those desiring further relaxation after the Convention should consider the possibility of visiting some of these places. If full information cannot be obtained from local passenger agents, the Convention Committee will be pleased to assist in every way. Arrangements should be made in advance so that proper accommodation may be assured.

HOTEL RESERVATIONS

The following hotels are available for members attending the Convention. Reservations should be made as soon as possible.

HOTELS—EUROPEAN PLAN

Hotel		Bath		Running Water	
		Double	Single	Double	Single
*Clifton	Ontario	$7.00	$4.00	$4.50	$2.50
Lafayette	Ontario	5.00	3.00	3.50	2.00
Prospect	New York	9.00	5.00	6.00	4.00
Imperial	New York	5.00	3.00	4.00	2.50
Watson House	New York	5.00 up	2.50 up	3.00	1.50
Temperance House	New York	5.00	3.50	4.00	2.50

*Convention Headquarters.

To those who may wish accommodations in Buffalo the Iroquois, Lafayette and Statler Hotels are available. High speed suburban trains between Niagara Falls, N. Y., and Buffalo leave every thirty minutes. Running time fifty minutes.

Pacific Coast Convention

VANCOUVER, B. C., AUGUST 8-11, 1922

The Eleventh Annual Pacific Coast Convention will be held in Vancouver, B. C., August 8 to 11, 1922, with headquarters at the Hotel Vancouver. This will be the fourth general meeting of the Institute this year, in accordance with the plan adopted by the Board of Directors last August of holding four general meetings each year.

The Convention Committee has been appointed by President McClellan as follows: John R. Read, chairman, 602 Bank of Nova Scotia Bldg., Vancouver; Frank W. MacNeill, Secretary, Canadian General Electric Company, Vancouver; C. N. Beebe, E. E. F. Creighton, T. H. Crosby, J. A. Fletcher, W. W. Fraser, J. Muirhead, L. P. Philpot, Frank Sawford, A. Vilstrup, and A. C. R. Yuill. This committee is making elaborate arrangements for the reception and entertainment of the members and guests attending the convention. The entertainment will include excursions and other outings, and several social functions. Special diversions will be provided for the ladies.

An interesting technical program has been prepared by the Meetings and Papers Committee, and will be announced in the July issue of the Journal, in which some of the papers will also be published. Advance copies of all the meeting papers will be available in advance of the meeting.

Further details regarding the convention will appear in the July Journal.

Marconi to Address Meeting

New York. On the evening of Tuesday, June 20, 1922, there will be a joint meeting of the New York Section of the A. I. E. E. with the Institute of Radio Engineers. The speaker for the evening will be Mr. Gughielmo Marconi who will present a paper entitled "Radio Telegraphy." The Institute of Radio Engineers will also present to Mr. Marconi its Medal of Honor for his pioneer work in the radio field. The meeting will be called to order at 8:00 p. m. in the auditorium of the Engineering Societies Building, 33 West 39th Street, New York.

Annual Meeting

ELECTION OF OFFICERS

The Annual Business Meeting of the A. I. E. E. was held in the Engineering Societies Building, New York, on Friday afternoon, May 19, 1922, President William McClellan presiding.

The annual report of the Board of Directors was presented. Pamphlet copies of this report were distributed at the meeting, and are available to any other members upon application to the Secretary of the Institute.

The report of the Committee of Tellers on the election of officers was presented (printed elsewhere in this issue), and in accordance therewith President McClellan announced the election of the following officers, whose terms will begin August 1, 1922:

President:	Frank B. Jewett, New York
Vice-Presidents:	
District No. 1	G. Faccioli, Pittsfield, Mass.
District No. 3	W. I. Slichter, New York
District No. 5	R. F. Schuchardt, Chicago
District No. 7	H. W. Eales, St. Louis (Reelected)
District No. 9	H. T. Plumb, Salt Lake City, Utah
Managers:	
	H. M. Hobart, Schenectady, N. Y.
	Ernest Lunn, Chicago
	G. L. Knight, Brooklyn, N. Y.
Treasurer:	George A. Hamilton, Elizabeth, N. J. (Reelected)

The above, together with the following hold-over officers, will constitute the Board of Directors for the next administrative year:—William McClellan, New York; A. W. Berresford, Milwaukee; N. W. Storer, Pittsburgh; C. G. Adsit, Atlanta; F. W. Springer, Minneapolis; Robert Sibley, San Francisco; F. R. Ewart, Toronto; L. E. Imlay, Niagara Falls; F. F. Fowle, Chicago; L. F. Morehouse, New York; Harold B. Smith, Worcester, Mass.; James F. Lincoln, Cleveland; E. B. Craft, New York; R. B. Williamson, Milwaukee; A. G. Pierce, Pittsburgh; Harlan A. Pratt, New York.

The wide geographical distribution of the Institute's Directors is indicated by the fact that twelve states and Canada are represented in the above list.

President McClellan made a brief address regarding the scope and condition of the Institute's activities, in which he pointed out the important changes in policy made during the past year, with reference to publications, the holding of a limited number of general conventions of the Institute each year and the discontinuance of the former monthly Institute meetings, thus placing all monthly meetings on the same basis, that is, holding them all under the auspices of the Institute Sections.

DINNER IN THE EVENING

On Friday evening, twenty-five officers, members of the Board of Directors, past-presidents of the Institute and the president-elect, met at dinner at the University Club.

The occasion afforded an opportunity for the officers and past-presidents to greet the president-elect, and to discuss informally the affairs of the Institute. President McClellan presided, and in his opening remarks presented briefly the facts in regard to the status of Institute work, and brought up many questions regarding policies of the future. Discussion was participated in by Past-Presidents Carty, Mailloux, Dunn, Wheeler, Buck, Berresford, Townley, Rice and Scott, and by President-Elect Jewett.

A. I. E. E. Directors' Meeting

The regular bi-monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, May 19, 1922.

There were present: President William McClellan, New York; Past Presidents A. W. Berresford, Milwaukee, Calvert Townley, New York; Vice-Presidents W. A. Del Mar, New York, N. W. Storer, Pittsburgh; Managers E. B. Craft, Harlan A. Pratt, W. I. Slichter, New York, G. Faccioli, Pittsfield, F. F. Fowle, Chicago, James F. Lincoln, Cleveland, F. D. Newbury, Pittsburgh, Harold B. Smith, Worcester, R. B. Williamson, Milwaukee; Secretary F. L. Hutchinson, New York.

Upon the recommendation of the Board of Examiners, the following action was taken upon pending applications: 177 Students were ordered enrolled; 187 applicants were elected to the grade of Associate; 15 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 11 applicants were transferred to the grade of Member; 4 applicants were transferred to the grade of Fellow.

Approval by the Finance Committee of monthly bills amounting to $23,005.83 was ratified.

Mr. C. E. Skinner, A. I. E. E. representative on the Executive Committee of the American Engineering Standards Committee, presented in person the proposed plan of cooperation of the A. E. S. C. with the Department of Commerce in the Department's contemplated campaign for the simplification of manufactured products, as requested by Secretary Hoover of the Department of Commerce in a letter to the A. E. S. C. dated May 4, 1922. After a brief discussion it was voted that the subject be referred to the technical committees for consideration and recommendation as to simplification that could be done in the particular field covered by each committee; that the committees be requested to report prior to the next meeting of the Board, schedules to be held during the Annual Convention in June; and that the A. I. E. E. representatives on the American Engineering Standards Committee act as a coordinating committee to prepare a comprehensive report of the recommendations of the technical committees, for presentation to the Board of Directors.

A report to the Board of Directors was presented from the Subcommittee on Translation into Foreign Languages, of the Standards Committee, advising that negotiations have been entered into for the translation of the next revision of the A. I. E. E. Standards, when completed, into the Spanish language, the translation to be financed by the Bureau of Standards, printed by the Department of Commerce, and distributed by the Government at a nominal charge, and requesting the Board's approval of this procedure. It was voted that the translation of the Institute Standards under the terms specified in the Subcommittee's report, be authorized.

Annual reports of the Board of Directors, the Treasurer, and various standing committees, were presented and accepted.

In accordance with Section 37 of the Constitution, the appointment of a Secretary was considered, for the administrative year commencing August 1, 1922; and Secretary F. L. Hutchinson was reappointed.

Upon the recommendation of the Sections Committee, authorization was given for the organization of a "Southern Virginia Section" of the Institute, to include Richmond and all the southern portion of Virginia.

Authorization was given for the establishment of a Student Branch at Marquette University, Milwaukee, as recommended by the Committee on Student Branches.

Professor Charles F. Scott was reappointed a representative of the Institute upon the Commission of Washington Award, for the term of two years ending June 1924.

A report was read, and ordered received and filed, from Mr. C. E. Skinner, A. I. E. E. delegate to the Conference on Engineering Education held at the Carnegie Institute of Technology, Pittsburgh, May 1-2, 1922.

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

Board of Directors' Report

FOR THE YEAR ENDING APRIL 30, 1922

The Annual Report of the Board of Directors of the A. I. E. E. was presented at the Annual Business Meeting of the Institute held in New York, Friday afternoon, May 19, 1922.

This report consists of a brief summary of the principal activities of the Institute during the year, including abstracts of various reports submitted by officers and committees, covering their respective branches of work. The more important matters referred to in the report have been, or will be, covered in much more detailed form in the JOURNAL, and therefore the report will not be published in full herein, but any member of the Institute may obtain a pamphlet copy upon application to the Secretary of the Institute.

The growth in Institute membership during the year is indicated in the following tabulation:

	Honorary Member	Fellow	Member	Associate	Total
Membership, April 30, 1921	6	541	1,903	10,765	13,215
Additions:					
Transferred		23	146		
New Member Qualified	1	1	114	1,646	
Reinstated		2	9	39	
Deductions:					
Died	1	5	11	45	
Resigned		3	20	187	
Transferred			14	155	
Dropped		1	30	461	
Membership, April 30, 1922	6	558	2,097	11,602	14,263

Net increase in Membership during the year.................... 1048

The activity of the Sections and Branches during the year, and the growth in the number of these organizations, also in the number of meetings held by them and in the aggregate attendance, are shown in the following statement:

	For Fiscal Year Ending						
	May 1 1916	May 1 1917	May 1 1918	May 1 1919	May 1 1920	May 1 1921	May1 1922
SECTIONS							
Number of Sections	32	32	34	34	36	42	45
Number of Section meetings held	.251	265	245	217	262	303	373
Total Attendance	28,553	31,299	34,614	25,837	30,741	37,823	54,378
BRANCHES							
Number of Branches	54	59	59	61	62	65	67
Number of Branch meetings held	360	368	268	156	360	443	439
Attendance	15,166	16,107	10,683	6,441	16,827	21,629	25,358

The Finance Committee's Report, together with the general balance sheet and detailed financial statements of the Certified Public Accountants who audited the Institute books, are included in the report. These statements show that the total income of the Institute during the year was $246,470.87, and the surplus for the year was $7,180.60.

Report of Committee of Tellers on Election of Officers

To the President,
American Institute of Electrical Engineers.

DEAR SIR:

This committee has carefully canvassed the ballots cast for officers for the year 1922-1923. The result is as follows:

Total number of ballot envelopes received........		5631
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI, Sec. 34, of the Constitution..........................	59	
Rejected on account of voter being in arrears for dues on May 1, 1922, as provided in the Constitution and By-laws........................	179	
Rejected on account of ballot not being enclosed in inner envelope, or being improperly marked, or on account of inner envelope bearing an identifying name, according to Art. VI, Sec. 34, of the Constitution.......................................	191	
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 34, of the Constitution..................	27	456
Leaving as valid ballots........................		5175

These 5175 valid ballots were counted, and the result is shown as follows:

For President

Frank B. Jewett	4641
*Farley Osgood	475
Blank	59

For Vice-Presidents

District	
No. 1. *North Eastern*	
G. Faccioli	4920
Blank	255
No. 3. *New York City*	
W. I. Slichter	4865
Blank	310
No. 5. *Great Lakes*	
R. F. Schuchardt	4215
C. I. Hall	674
*J. C. Parker	105
Blank	181
No. 7. *South West*	
H. W. Eales	4808
Blank	367
No. 9. *North West*	
H. T. Plumb	4226
G. E. Quinan	733
Blank	216

For Managers

H. M. Hobart	4833
Ernest Lunn	4784
G. L. Knight	4654
*W. M. McConahey	202
C. S. McDowell	607
Blank	445

For Treasurer

George A. Hamilton	4985
Blank	190

*Candidate withdrew prior to printing of ballots.

Respectfully submitted,

J. B. Bassett, *Chairman* R. R. Kime
William V. Howard S. D. Kutner
Wm. Hetherington, Jr. E. E. Dorting J. D.
E. A. Hester *Committee of Tellers.*

Frank B. Jewett

PRESIDENT-ELECT OF THE A. I. E. E.

Frank B. Jewett has been elected president of the American Institute of Electrical Engineers for the year beginning August 1, 1922, as announced in the report of the Committee of Tellers published elsewhere in this issue. Dr. Jewett, although just reaching the prime of life, has long since been recognized both at home and abroad as one of the foremost telephone engineers of our time.

He was born in 1879 at Pasadena, California, and in 1898 was graduated from the Throop Polytechnic Institute, now the California Institute of Technology. From the University of Chicago, where he spent some years as research assistant to Professor A. A. Michelson, he received the degree of Ph. D. Later he was instructor in physics and electrical engineering at the Massachusetts Institute of Technology, and in 1904 joined the staff of the American Telephone and Telegraph Company. In this position, Mr. Jewett worked in a field in which his brilliant attainments and fundamental scientific training qualified him admirably for the practical engineering work and scientific development and research which he was called upon to do.

In all of the remarkable developments in the telephone art which have taken place in the last fifteen years and which include the establishment of the transcontinental telephone line, and talking for the first time by radio across the Atlantic, Dr. Jewett has been actively concerned, and because of his scientific skill and administrative abilities, his contributions to these and many other notable achievements have been of the first order.

In 1912, Mr. Jewett became assistant chief engineer of the Western Electric Company, and in 1916 was made chief engineer, having charge of the research laboratories, which carry out the experimental work for the Bell system; he also had supervision of all the engineering work required in connection with the manufacturing activities of the Western Electric Company. These laboratories are the most extensive of their kind, employing hundreds of workers and scientists whose activities cover the entire range of telephone development.

He is now vice-president of the Western Electric Company, and his duties have been extended to include the supervision of all the manufacturing operations of that company in America, together with the direction of its sales and the distribution of its manufactured product.

Frank B. Jewett

At the outbreak of the war Dr. Jewett volunteered for service in the Army and was immediately commissioned as Major in the Signal Corps, and placed in charge of the development of numerous scientific devices for the use of the Signal Corps. Prominent among these was the radio telephone, for use in connection with aircraft. He served as a member of the Anti-Submarine Board of the U. S. Navy, and took a notable part in the development of methods and apparatus for combating the submarine activities of the enemy. He was promoted to the grade of Lieutenant-Colonel, and for his service in the Army and his other war activities he received from the United States Government the Distinguished Service Medal.

He is the author of numerous scientific and engineering papers, and is one of the foremost among those who have done so much

to advance electrical engineering to its present high standing among the learned professions.

Dr. Jewett is a Fellow of the Institute, having joined in 1903. He has served the Institute as manager, vice-president, member of the Executive Committee and as an active worker on some of its other important committees. He represents the Institute on the Board of Trustees of the Engineering Foundation and is chairman of the General Advisory Board on Electrical Engineering of the Engineering Division of the National Research Council.

He is a director of the Western Electric Company, Inc., and of the International Western Electric Company, Inc.; vice-president of the Manufacturers' Junction Railway; and past-president of the New York Telephone Society. He is a member of numerous scientific societies, including the National Academy of Sciences, the National Research Council, the American Physical Society, and the American Association for the Advancement of Science.

Appointment of Former Enlisted Men as Officers of Engineer Reserve Corps

During the early months of our participation in the World War, there were many engineers and others of known education, ability, and experience who waived the opportunity to obtain commissions and enlisted in the engineer regiments that were being recruited for immediate service in France. Thus it happened that in many of these regiments a large proportion of the rank and file were graduates of colleges or technical schools, with all the qualifications requisite for engineer officers. In the event of a future emergency such men by reason of their professional accomplishments combined with their military experience would be of inestimable value as engineer officers, and while it is true that they would come forward in time of need, even though not enrolled in the Reserve Corps, their value nevertheless would be greatly enhanced should they accept commissions now, for by this means they would keep in touch with military developments.

The present project for six volunteer field armies for the National Defense calls for an ultimate strength of 9000 engineer officers. The present total, including Regular Army, National Guard, and Organized Reserve, is less than 4000. It is the policy of the War Department to enroll in the Engineer Section of the Officers' Reserve Corps those who served as enlisted men during the late war, provided that they have the technical qualifications to warrant such appointment. They will be appointed in grades commensurate with their positions and responsibilities in civil life. Men of this type can be enrolled in the higher grades without affecting in any degree the appointment as Second Lieutenants of the young and inexperienced graduates of the R. O. T. C. units of our universities.

In considering applications of enlisted men for commissions in the Engineer Reserve Corps, examining boards will exercise a wide discretion and will give great weight to professional and technical ability rather than a detailed knowledge of military regulations. Candidates for appointment will be expected to demonstrate by their past achievements and present worth that they have the capacity to adapt themselves to the military system should occasion arise, but they will not be rejected because of present unfamiliarity with military subjects alone. Officers so appointed will be given an opportunity to receive the necessary instruction in military subjects before they are called upon for actual service in their grades or before they are eligible for promotion to the next higher grade.

Detailed information may be had by writing to the Chief of Engineers, Washington, D. C., or to the Corps Engineer at the Headquarters of any of the nine Corps Areas into which the country is divided.

Citizens' Military Training Camps

Citizens' Military Training Camps are to be conducted by the War Department during the period from Aug. 2 to 31, 1922. Indvidual camps will be established for infantry, cavalry, coast artillery, field artillery, signal corps and engineers, the latter at Camp Dix, N. J. The camp will be divided into three courses according to age and previous military experience, if any. Age limits vary from 17 to maximum of 35. The government will pay the expenses of those attending, including transportation. Too much emphasis can not be attached to these camps, as they are the only direct connection between our present inadequate force and the general public. Those attending the engineers' camp will receive splendid elementary instruction in engineering along with thirty days of healthful outdoor life. Complete information may be obtained by addressing, Recruiting Adjutant, Second Corps Area, Governors Island, N. Y.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—C. B. Andrews, c/o Mrs. G. F. McKay, Box 35, Ben Lomond, Calif.

2.—Eugene A. Baerer, Box 253, Kenvil, N. J.

3.—F. J. Coffey, Alaska Gastineau Mining Co., Perserverance Mine, Thane, Alaska.

4.—Waldo C. Cole, 410 Mills Bldg., El Paso, Texas.

5.—O. A. Darnell, 409 East 5th St., Los Angeles, Calif.

6.—John F. Donohue, 45 2nd St., Newark, N. J.

7.—Edward F. Doyle, c/o Nat'l Conduit & Cable Co., Hastings-on Hudson, N. Y.

8. M. V. Eardley, P. O. Box 664, Long Beach, Calif.

9. Earl V. Edkins, 5827 Trinity Place, W. Philadelphia, Pa.

10.—F. W. Erikson, 214 University Club Bldg., St. Louis, Mo.

11.—Victor R. Fisher, U. S. Sumbarine Base, Coco Sols, Canal Zone.

12.—Frank Hempton, P. O. Box 431, Gallup, N. M.

13.—Leonard Knowles, 411 South 56th St., Philadelphia, Pa.

14.—Wen Siang Lu, Y. M. C. A., Lynn, Mass.

15.—R. W. Seem, 633 West 74th Street, Los Angeles, Calif.

16.—J. Hubert Shanhan, 527 Morris Ave., Elizabeth, N. J.

17.—F. W. Smith, 500 Todd St., Wilkinsburg, Pa.

18.—Theo. V. Tillinghast, c/o Plano Toy Co., Plano, Ill.

National Exposition of Chemical Industries

NEW YORK, N. Y., SEPTEMBER 11-16, 1922

The Eighth National Exposition of Chemical Industries will be held in the Grand Central Palace, New York City, during the week of September 11 to 16 inclusive. It will follow immediately upon the Fall Meeting of the American Chemical Society. "Raw Materials, Machinery, Products" is the way the Exposition is described and is intended to carry this main impression. The raw materials are exhibits of the natural resources from out of the earth and above the earth. The machinery exhibits consist of apparatus and equipment and instruments for control, precision, recording, gaging, measuring, and machinery for every mechanical operation in the manufacture of products from the raw materials. The products themselves are the finished products and the exhibits will contain those of organic, and inorganic origin, of solid, liquid or gaseous form, and of every conceivable nature. Many new things upon which manufacturers

were working when the War ended and which have been since more leisurely perfected, will be shown for the first time.

The program of the exposition has been outlined and it may be expected to compare fully with the high standards of the preceding expositions. As has been the custom there will be exhibits of motion pictures covering all phases of the chemical industries and the exposition will hold many interests for every visitor.

The office of the managers, Charles F. Roth and Fred W. Payne, is in the Grand Central Palace, New York City and inquiries should be directed to them there.

The Institute of Radio Engineers

MEETING IN NEW YORK, JUNE 7, 1922

Members of the A. I. E. E. are invited to attend a meeting of the Institute of Radio Engineers on Wednesday evening, June 7, at 8:15 p. m., in the Engineering Societies Building, 29 West 39th Street, New York City. A paper on "The Super-Regenerative Method of Amplification" by Mr. Edwin H. Armstrong will be presented, and a new and interesting system of reception will be explained and demonstrated experimentally.

American Engineering Council

EMPLOYMENT COMMITTEE

The Committee on Procedure of American Engineering Council has approved the following appointments by President Mortimer E. Cooley to the Employment Committee: E. S. Carman, Cleveland, chairman; W. J. Fisher, York, Pa.; W. E. Rolfe, St. Louis; Boyd Fisher, Boston; Clayton Pike, Philadelphia.

PITTSBURGH MEETING, MAY 26-27, 1922

The Executive Board of the American Engineering Council of the Federated American Engineering Societies held a very encouraging meeting in Pittsburgh on May 26 and 27. The board members reported organized engineering conditions in their respective regions, and the conclusion was reached that the Federation had progressed to the point where its permanence and growth were assured. President Mortimer E. Cooley who presided over the meeting, said that everywhere on his recent trip throughout the country it was evidenced that the Federation idea was growing, and that substantial additions to the membership might be expected in the near future.

The sessions were held in the rooms of the Engineering Society of Western Pennsylvania at the William Penn Hotel. The members of the board were guests of this society at a dinner on Friday evening, May 26, and on Saturday evening were entertained at dinner by the engineering alumni of the University of Michigan.

Registration of engineers, employment, federal water power, government reorganization and reforestration were among the leading topics disposed of by the board after discussions more thorough and more inspiring than at any board meeting yet held.

Registration of Engineers

One of the most important acts of the board was the adoption of the report of the Committee on Registration of Engineers. The report as adopted contains the statement "that the reasons which justify the registration of engineers responsible for public works do not apply to mining engineers." It follows:

In considering matters of government as affecting the engineering profession of the United States, the ancient principle which states "that country is governed best which is governed least," has been accepted by your committee as representing ideal conditions, and it holds that in an ideal social organization, where man can be left free to follow the trend of his individual bent without resulting injury to his fellow, each should be free to follow such calling as he may adopt, without state interference or regulation.

Engineering in the United States under absolutely untrammeled conditions in the past, has developed effective skill and a high degree of constructive ability among its practitioners, during which period the provisions for safety have been adequate under average conditions, and the failures which may have occurred have not been rated serious enough to demand legal control.

Within the past few years, however, a widely supported movement has appeared, resulting in the passage of laws requiring licensing or registration of engineers in various states and attempts at similar legislation in others.

It is, therefore, a condition and not a theory which is before the engineering profession for consideration, and the F. A. E. S. should decide whether it will lend the weight of its advice upon principle only or will accept and travel with tendencies.

The registration or licensing of engineers with consequent elimination from practise of all not registered, can be supported upon only two grounds:

(a) The benefit of the profession

(b) The good of the public

Your committee has grave doubts whether licensing can benefit the profession enough to justify the cost and annoyance of the proposed measure. Further, your committee holds it would be beneath the dignity of engineers to fence themselves against qualified competition by the artificial barrier of a statute.

Your committee, while recognizing that required registration might not have been recommended ab initio believes that the plan has now reached such development as to deserve consideration and possible direction by the F. A. E. S. (or A. E. C.).

Therefore

Your committee recommends to the A. E. C. (F. A. E. S.) an expression of opinion that such legislation may properly cover engineers and architects charged with responsibility for public works.

Your committee is agreed that the reasons which justify the registration of engineers responsible for public works do not apply to mining engineers.

Your committee is unable to agree as to the wisdom or unwisdom of registration of engineers engaged in other classes of work.

Registration laws should provide reciprocity of registration admitting to practise engineers registered in other states and should further provide for the admission to practise of properly accredited engineers from states having no registration laws.

Registration laws should provide for classified registration, that the certificate may indicate those branches of engineering in which the registrant is qualified to practise.

Employment Service

It was decided that the employment service which is now maintained by the Council in New York would be turned over to the administration and control of the four Founder Societies. The Employment Committee of the Council is to go on with its investigation of the employment question, and to study the possibility of coordinating existing and local employment services with a big national service.

Improved business conditions reflected by the employment situation nationally among engineers were reported by Executive Secretary L. W. Wallace of Washington.

Water Power Problem

The federal water power situation is in a critical condition, making immediate constructive action by the government necessary in order to conserve the public interests. The board, after a thorough discussion of the problem, adopted a resolution directing the Committee on Water Power to place before President Harding the facts of the situation. The board's action at this time, it was stated, was prompted by the "Federal Water Power Commission's lack of effective and permanent personnel."

Forest Conservation

A national movement to conserve the nation's forests, in which engineers, the U. S. Forestry Service, the forestry services of the states, universities and technical schools, and other groups such as the farmers, the railroads and lumbermen, shall pool

their efforts, was set in motion by the engineers. The work will be in charge of the Reforestration Committee of the Council.

Moving picture interests will be asked to aid in arousing popular interest in the need of saving the nation's forests and a conference to bring this about is planned between Will H. Hays and President Cooley.

Reports on the forestry situation in various states were received. President Cooley asserted that there were 85,000,000 acres in the United States that were fit only for wood and that there were 245,000,000 acres partly fit for wood. In Georgia, Alabama, South Carolina, Mississippi, Louisiana, Arkansas and Texas, he said, there was an area equal to Georgia, Alabama and Mississippi once occupied by forests now denuded and of which only 20 per cent are now available for agriculture.

Flood Control

The national problem of flood control was described as of vital importance, and it was decided to cooperate with other agencies in finding a solution, involving the establishment of a national hydraulic laboratory. The recent disastrous floods along the Mississippi caused the question to be brought before the engineers. Senator Ransdell of Louisiana and John R. Freeman of Providence, R. I., it was announced, are at work devising general plans upon which a comprehensive investigation of the whole problem may be based.

Standard Forms of Contracts

The board voted continued cooperation with the numerous organizations interested in types of government contracts. A study was directed of a proposed form of universal contract agreement as applied to railroad construction and drafted by a joint conference on standard construction contracts.

Government Reorganization

The board pledged its support to President Harding in his plan of government reorganization. In adopting the report of its Committee on Public Affairs the board determined, in the event of the failure of the President's efforts to bring about greater economy and efficiency in national affairs by a regrouping of federal functions, to press independently a nationwide movement for the establishment of a Department of Public Works.

Work Periods in Continuous Industries

The Council's Committee on Work Periods in Continuous Industries reported much progress in a national survey of the two-shift day in American industries. This survey, called the most extensive of its kind ever made, has been in progress for more than a year, and purposes an exposition of industrial conditions which shall form a basis for establishing the relative merits of three shifts of eight hours each and two shifts of twelve hours each. An enormous amount of data has been accumulated in various industries, and the board voted to refer it to the Committee on Procedure, which will direct the work of putting the material contained in the findings into shape for publication. The gathering and preparation of this material in form available to the general public was declared to be one of the most momentous tasks ever carried on under the auspices of American engineering.

The steel industry came in for consideration, and it was announced that progress is being made in an investigation to determine methods of converting steel plants in engineering aspects as to metallurgy and production from two to three shifts. Approval of Bradley Stoughton of New York, formerly secretary of the American Institute of Mining and Metallurgical Engineers, as director of this field study was voted by the Executive Board.

Survey of Business Cycles

Successful accomplishments of the study of business cycles conducted by the Council with the assistance of 150 engineering groups and in cooperation with the Department of Commerce were reported. The data gathered are now being compiled in Washington and will be available to further the plans of the President's Committee on Unemployment in its study of cyclical depressions.

Other Matters

Jurisdictional awards in labor, patent legislation, an International Engineering Congress, aerial research, engineering representation on the Civil Service Commission, foreign relations, waste in agriculture and plans for more intensive engineering organization, as proposed by Herbert Hoover, were other topics before the Council, which contemplates closer and more active cooperation with the Federal government in public questions involving engineering experience.

The National Board for Jurisdictional Awards was strongly upheld, Executive Secretary Wallace of the Council declaring that it is one of the fundamental bases upon which the rehabilitated building industry for the future must rest.

A report from the Patents Committee of the Council headed by Edwin J. Prindle of New York voiced opposition to the Stanley and Ladd bills as detrimental to American invention and industry.

Next Meeting in Boston

The Executive Board, after declaring its readiness to serve in the public interest wherever engineering experience was involved, adjourned to meet in Boston in the fall, the date to be fixed by the Committee on Procedure.

Personnel Research Federation

The Personnel Research Federation organized a year ago under the auspices of the Engineering Foundation and the National Research Council to coordinate the efforts of the 250 scientific, engineering, labor, management and educational bodies which are studying personnel problems in the United States today, reports a year full of progress. The primary object of the organization, to act as a clearing-house of information for the various agencies carrying on investigations in personnel work, and to bring these agencies together for interchange of ideas, so that they might be of mutual benefit to one another, and avoid duplication of effort, was greatly furthered by a survey of the existing agencies, describing their scope, methods and activities, made by J. David Thompson, and issued as a bulletin of the U. S. Bureau of Labor Statistics.

During the winter months following the preliminary conference which had brought the organization into being, Dr. W. V. Bingham of the National Research Council and Alfred D. Flinn, secretary of the Engineering Foundation, took steps to find out how many groups would be interested in joining a permanent organization, and after this preliminary survey a second conference was called on March 15, 1921. At this conference the National Research Council, the Engineering Foundation, the American Federation of Labor, Bryn Mawr College, the Bureau of Industrial Research, Carnegie Institute of Technology, the National Committee for Mental Hygiene and the University of Pennsylvania became charter members.

The first annual meeting was called in November 1921, in Washington, and was attended by fifty persons, twenty-five of whom represented memberships in the Federation. Two new active memberships were Dartmouth College and the Bureau of Vocational Information. The U. S. Bureau of Labor Statistics, the U. S. Bureau of Mines, the U. S. Civil Service Commission and the U. S. Public Health Service had become cooperating members, as well as Harvard University, Northwestern University and the University of Chicago.

Since this general meeting, the central office has been continuing its efforts to make the Personnel Research Federation an organization of real service. It has been attempting to secure funds for a more permanent establishment and for furthering certain specific inquiries. It has arranged for the publication of a Monograph Series to provide an outlet for the work of the active

members and other researches of importance. The earlier numbers will deal with job analyses and occupational description, in studies aiming at the development of a technique of occupational description and the establishment of a standard occupational terminology.

Another enterprise of the central office is the *Journal of Personnel Research*, the first issue of which appeared in May. This number contained the following articles: "Reasons and Plans for Research Relating to Industrial Personnel," by President Angell of Yale University; "Development of Personnel Research Federation" by Alfred D. Flinn; and "Basic Experiments in Vocational Guidance," by C. S. Yoakum. Samuel Gompers will contribute an article on "Cooperation of Workers in Study of Industrial Personnel Matters," in an early issue and others promised are, "Intelligence of Policement" by L. L. Thurstone; "What is Personnel Research?" by Robert M. Yerkes.

Some idea of the problems which Federation members are attempting to solve may be gathered by this list of studies in which various organizations are engaged this year: Job analyses of managers; interest analyses, will-temperament traits and vocational aptitudes; selection, training and supervision of salesmen; women in chemistry; studies in hygiene and safety in a variety of industries.

American Engineering Standards Committee

SURVEY OF SIMPLIFICATION NEEDS UNDERTAKEN

At the request of Secretary Herbert Hoover, of the Department of Commerce, the American Engineering Standards Committee will undertake at once a canvass to determine what simplification in manufactured products is most needed and most desirable. This canvass will be conducted through the engineering and technical bodies having representatives on the Committee or cooperating in its work. The survey of simplification or standardization needs and possibilities will extend into almost every industry in America.

What relationship should exist between the simplification work of the Department of Commerce and the standardization work of the American Engineering Standards Committee has been the subject of considerable discussion. It is clear now that there will be no duplication or overlapping. There seems to be general recognition of the fact that simplification of product and improvement of process are to a large degree only other words for standardization; that they are standardization put to work.

The executive committee of the A. E. S. C. has, by resolutions, pledged the cooperation of the committee to the Department of Commerce. Representatives of the committee recently held a conference on the subject with Mr. Hoover at Washington. Subsequently an arrangement was made for permanent exchange of representatives between the two organizations so that there may be the closest possible cooperation between the Commerce Department's division of simplified practise and the American Engineering Standards Committee.

PERSONAL MENTION

E. H. Flath has left the Western Electric Co., New York, and will teach in the Georgia School of Technology, Atlanta.

Elbert G. Allen, of the Philadelphia Rapid Transit Company, has been appointed chief engineer of that company.

Anson W. Burchard, a vice-president of the General Electric Company, has been elected vice-chairman of the Board of Directors of that company.

J. R. Lovejoy, a vice-president of the General Electric Company, was recently elected a director of the company. Mr Lovejoy is a Fellow of the Institute.

Roy B. Kile is located with the Gulf Refining Company, Port Arthur, Tex. He was previously in the engineering department of the New York Edison Company.

J. E. Housley, until recently assistant power superintendent with the Aluminum Ore Company, E. St. Louis, Ill., is with the Aluminum Company of America in Kansas City, Mo.

Vreeland Y. Leonard, of Indianapolis, has become manager of the utilities department of the Interstate Public Service Company, Columbus, Ind. He will have charge of the local electric lighting plant.

Arthur L. Mullergren, consulting engineer, has opened offices in Kansas City, Mo., and New York City. He was until recently a member of Benham & Mullergren, consulting engineers of Kansas City.

C. R. Rock, formerly contracting engineer of Canton, Ohio, is now connected with McCarthy and Rock, general contractors, of Potsdam, N. Y., in the capacity of superintendent of contruction.

Howard W. Thomas has been transferred from the Boston Navy Yard, Plant Dept., to the Eleventh Naval District, San Diego, Cal., as assistant inspector of electrical material, Bureau of Yards and Docks.

Edward M. Claytor, formerly chief engineer of The Electric Products Company, Cleveland, resigned that position in April and is now located in the control division of the Westinghouse Electric & Manufacturing Company, East Pittsburgh.

Merritt B. Miller has resigned his position in the design department of the Westinghouse Electric & Manufacturing Company at East Pittsburgh, Pa., to accept a position with the Central Michigan Light & Power Company, Alma, Mich.

W. D. A. Peaslee has been appointed chief engineer of the Belden Manufacturing Company, Chicago. Mr. Peaslee was captain in the Engineer Corps during the War, and since then until last fall was with the Jeffery-Dewitt Insulator Company, Huntington, W. Va.

David D. Gibson, Jr., has recently become connected with Sanderson and Porter Corporation as designer on electrical extensions to the Windsor power station at Power, W. Va., Mr. Gibson was previously engaged with the New York Edison Company on the design of the 32nd Street substation.

Carl G. Schluederberg has been elected president of the American Electrochemical Society. Mr. Schluederberg returned recently from a three months' trip in South America, where he made a study of business conditions for the Westinghouse Electric and Manufacturing Company.

Carl Hering was made an honorary member of the American Electrochemical Society at its meeting in Baltimore April 27-29. Dr. Hering is one of the founders of the society, and has contributed much toward its growth. He is prominent also in the activities of the A. I. E. E., of which he was president during the year 1900-1901.

William Paterson Van Wyck has resumed his position as purchasing agent of the Radio Corporation of America, New York City, after an absence of some months. Mr. Van Wyck joined the company in 1920 and supervised the purchases for the construction of their large radio central plant at Port Jefferson, L. I., which was erected by the J. G. White Engineering Corporation.

A. S. Kalenborn is now with the California-Oregon Power Company in Medford, Ore., on engineering problems connected with the building of a hydroelectric plant unit, and the construc-

tion of a 116-mile transmission line to Springfield, Ore. Mr. Kalenborn recently returned from Peru where he was in charge of the hydroelectric department of the Cerro dePasco Copper Corporation in the Andes Mountains near Lima.

E. A. Wilcox has resigned his position as vice-president and sales manager of the Pittsburgh Electric Furnace Corporation and is located in Los Angeles, Cal., where he has established a manufacturers' agency, specializing in electrical and mechanical machinery and equipment. During the war Mr. Wilcox served overseas as captain in the U. S. Army, and previous to that time was manager of the Public Service Company of Oklahoma.

David B. Rushmore, chief engineer of the power and mining department of the General Electric Company, has recently been appointed to the staff of consulting engineers of the company. Mr. Rushmore has been connected with the General Electric Company for seventeen years, having been previously with the Stanley Electric Manufacturing Company of Pittsfield, which became a part of the General Electric organization in 1905. He is a Fellow of the Institute and has been a manager and a vice-president. He is a member of a number of other societies and organizations both here and abroad.

Frederick Krug has accepted a position with the Porto Rico Railway, Light and Power Company, as superintendent, La Plata Hydroelectric Plants, San Juan, Porto Rico. He resigned his position last fall with the New York and Hondural Rosario Mining Company, San Juancito, Honduras, C. A., where he had been assistant superintendent and acting superintendent of the electrical department since 1917, except for some time spent in war service as instructor at the Carnegie Institute of Technology and a short time as sales engineer with the Crocker-Wheeler Company, Ampere, N. J.

Alex. C. Humphreys and Alten S. Miller have withdrawn from active participation in the business of Humphreys & Miller, Inc., New York City, and Robert O. Luqueer of that company has joined with Alfred E. Forstall to form the partnership of Forstall, Robison and Luqueer, which will take over the interests of the company. The firm of Humphreys & Miller, Inc., was successor to Humphreys & Glasgow, of London. Dr. Humphreys became senior member of this firm in 1892, and continued as president of Humphreys & Miller, Inc., until the present time. He will continue his duties at the Stevens Institute of Technology, of which he has been president for a number of years.

K. A. Pauly has been appointed head of the power and mining department of the General Electric Company, succeeding D. B. Rushmore, now of the consulting engineering department. Mr. Pauly became connected with the General Electric Company in 1899, when he entered the G. E. test. He left the test in 1901 to enter the induction motor designing department, and in 1905 entered the power and mining engineering department, becoming head of the steel mill section. He is a member of the Institute, and belongs also to the American Institute of Mining Engineers, the American Mining Congress, and the Association of Iron & Steel Electrical Engineers.

Gerard Swope has been elected president of the General Electric Company to succeed E. W. Rice, Jr., who has become honorary chairman of the Board of Directors. Mr. Swope was formerly president of the International General Electric Company. A graduate from the Massachusetts Institute of Technology in 1895, he first entered the employ of the Western Electric Company in Chicago, working his way up from the shops to an executive position. In 1908 he came to New York as general sales manager of the company, and in 1913 was elected vice-president. He severed this connection the first of January, 1919 to become president of the International General Electric Company. Mr. Swope joined the Institute in 1899.

Charles A. Coffin has retired as chairman of the Board of Directors of the General Electric Company. Mr. Coffin has been connected for forty years with the development of the corporation and was founder and creator of the company and its predecessor, the Thomson-Houston Company. He will continue as a director of the company, to give attention to its problems. The new chairman is Owen D. Young, who has been vice-president of the company for a number of years. Mr. Young, a lawyer by profession, is connected with a number of other organizations in a directing capacity, being chairman of the board of directors of the Radio Corporation of America, director of the Electric Bond and Share Corporation, and director of the Bankers Trust Company. Mr. Coffin is one of the early members of the A. I. E. E., which he joined in 1887.

E. R. Shepard, of the Bureau of Standards, has retired from the Bureau and will devote his time to consulting work. Mr. Shepard is well-known in connection with the electrolysis research and field surveys of the Bureau, and will continue the same kind of work under his own name. A graduate from the University of California in 1904, he received the degree of M. A. from Harvard University in 1906. He was then associated with Stone & Webster for two years, and from 1909 to 1914 taught electrical engineering at the Oregon Agricultural College, which position he resigned to take up his present line of work at the Bureau of Standards. He is the author of a number of published articles, among them being some important papers issued by the Bureau of Standards on rail-bonds and joints and track insulation. He is a member of the American Committee on Electrolysis, and has been active in connection with its publications and research work. He will conduct his business in Washington, D. C.

E. W. Rice, Jr., president of the General Electric Company for the past eight years, has retired from that position with the purpose of devoting his time to the general engineering problems of the company rather than to the duties of detailed organization and management. He will become honorary chairman of the Board of Directors, a newly created position. Mr. Rice has been in active electrical engineering work since 1880, when he became associated with Prof. Elihu Thomson as his assistant. In 1884 he became general superintendent and consulting electrician with the Thomson-Houston Electric Company. When this company was united with the Edison Company to form the present General Electric Company, Mr. Rice became identified with the corporation, and has been prominent in its activities since, becoming in 1893 chief engineer, and three years later, third vice-president of the company. He was made president in 1914. Mr. Rice is a member of a number of scientific societies, being a Fellow of the A. I. E. E., of which he was president, 1917-1918. Harvard University conferred upon him the honorary degree of Master of Arts in 1903, and in 1906 Union University conferred upon him the degree of Doctor of Science.

Obituary

Herbert Stanley Miller, of Elizabeth, N. J., died in a hospital in Elizabeth on May 7, 1922, following an operation for appendicitis. Mr. Miller was born in Jersey City, December 31, 1869, his family moving to Elizabeth while he was still an infant. He was graduated from the Massachusetts Institute of Technology in 1892, and the next year took a position with the Diehl Manufacturing Company of Elizabeth, becoming secretary-treasurer when that firm was incorporated in 1896. He remained with the Diehl firm, engaged in engineering design and general construction work, until 1914, in which year he became affiliated with the Lake Torpedo Boat Company. Soon becoming president of this company, he held this office until the time of his death. Mr. Miller joined the Institute in 1899. He belonged also to the Technology Club and the Republican Club of New York, and the Elizabeth and Suburban Clubs of Elizabeth.

Edward Robert Tracy, of the Pacific Tel. & Tel. Company, Sacramento, Cal., died on March 1, 1922, with plural-flu-pneumonia. Born Nov. 9, 1890, in San Francisco, Mr. Tracy had just started his engineering career at the time of his death. In 1913 he completed the four-year course at the College of Hawaii, receiving a B. S. degree. He then had several years of commercial engineering and switchboard engineering experience in Portland, Ore., with the Pacific Tel. & Tel. Co., and in the early part of 1920 completed a four months' course in transmission engineering with that company. Later in 1920 he became division transmission engineer with the company in Sacramento. Mr. Tracy was an Associate of the Institute, which he joined in 1920.

Frederick Garfield Wiswell, chief draftsman with the Puget Sound Power & Light Company, Seattle, Wash., died on April 22, 1922. Mr. Wiswell was born in Montreal, Can., March 20, 1883. He did not attend college, but took the student's course with the General Electric Company in Lynn, Mass. From 1908 until 1916 he was electrical and mechanical draftsman for the Seattle-Tacoma Power Company and the Puget Sound Traction, Light & Power Company, in 1916 becoming chief draftsman in the engineering department of the Puget Sound Traction, Light & Power Company, now the Puget Sound Power & Light Company, of Seattle. His early death cut short a career of much promise. Mr. Wiswell became an Associate of the Institute in 1920.

Benjamin H. Elkins, superintendent of the Mallison Power Company, South Windham, Me., died April 21, 1922. Mr. Elkins was born in Jackson, N. H., August 3, 1863, and received his electrical engineering education through the International Correspondence School, completing the course in 1905. In 1890 he started to work with the N. E. Wiring & Construction Company, Boston which soon after was the Edison General Electric Company and then the General Electric Company. From 1893 to 1897 he was foreman in the construction department, Boston office. He left to enter the employ of the Bath Gas & Electric Company, Bath, Me., where he remained a year, and then was engaged for two years with the Consolidated Electric Light Company of Maine, Portland, Me. In 1900 he became connected with the Mallison Power Company, where he remained until the time of his death. Mr. Elkins joined the Institute in 1908.

Frank P. Lewis, electrical superintendent of the U. S. Navy Yard, New York, died at his home in Brooklyn, N. Y., April 7, 1922. Mr. Lewis was born in Memphis, Tenn., March 7, 1869, and attended school at the Raleigh Academy, Raleigh, N. C. He then had ten years' experience in building and operating electric railways with the Sprague Electric Company, Edison Electric Company, and Sprague, Duncan & Hutchinson, Ltd., during which time he supervised the installation of complete power plant equipment line construction and equipment of cars on street railroads in various cities. In 1898 Mr. Lewis was appointed a master electrician of the Navy Yard, N. Y., which at that time had five master electricians in various departments. The electrical activities of the yard were gradually consolidated, however, and in 1909 he was made master electrician of the yard, the position he held until the time of his death. His work included the installation of electrical equipment aboard U. S. battleships, the installation, care and operation of all yard motors, and the operation and repairs of power house equipment. During the World War there were approximately 1700 employees, with 70 subordinate supervisors, under his immediate direction, and he was responsible for all electrical work on vessels at the yard, on transports at the army piers, at the Brooklyn and New York water fronts, and at stations in the vicinity. His title at this time became electrical superintendent. His death was sudden and much regretted by all who knew him. Mr. Lewis joined the Institute in 1910.

Hints on Job Getting

The following article has been prepared by the New York Volunteer Employment Committee. This group is made up of men registered with the Engineering Societies Employment Service and is chiefly engaged in canvassing employers of engineers in and about New York City for the purpose of bringing to their attention the valuable service offered without charge by the bureau.

The experience gained by this committee in interviewing hundreds of employers and thousands of employees seems to prove that the average unemployed engineer of today passes through three stages before making a new connection.

The first may be likened to that of a chicken which has recently been deprived of its head. First comes the severing blow of discharge quickly followed by a wild outpouring of hastily prepared and ineffective letters, fit only for the waste basket; and a mad aimless rushing hither and thither after jobs for which the unfortunate is totally unfitted. Should anyone dare to offer the kindly suggestion that he is reaching for something beyond his grasp, the would-be applicant sees a diabolical attempt to keep him out of work and bull-headedly insists upon having his way; blindly ignoring the fact that he is wasting his time and hurting the Bureau.

Meeting with no success he is overcome with an enervating feeling of self-pity, and proceeds to give a most excellent imitation of Sir Isaac Newton discovering the law of gravity. While the achievements of great scientists are always worthy of imitation by engineers, there is very little chance these days of a pretty little cotton-wrapped job gently falling into the lap of any man. At this stage he spends a goodly part of his time in composing bitter arraignments of the inefficiencies of the Bureau (ignorant perhaps of the fact that his contribution towards its support amounts to just 25 cents per year), and is quite firmly convinced that the hand of both God and man is turned against him.

Finally, he reaches the third stage where he decides to quit imitating the ostrich, withdraws his head from the sand of ignorance and personal prejudice and faces the cold hard facts in the light of day Now something can be done to help him.

To get a job one must sell one's services. Unfortunately the prospect of having to go out and attempt a sale seems to throw most engineers into a blind unreasoning panic. This is due, doubtless, to a childlike acceptance of that most fallacious and weak-minded, though generally accepted, statement that an engineer cannot make a good salesman. And why not, pray? Surely a man who understands human nature, knows his goods, thoroughly believes in them, and displays a reasonable amount of enthusiasm in presenting them should stand a good chance of making a sale. The trouble with the unemployed engineer is that he doesn't know his goods, consequently hasn't a strong belief in them and instead of presenting them with a show of sincere enthusiasm, tries to cover these defects with a bluff; thus inevitably appearing either as a "know it all" or a charity seeker.

When an employer desires a man to fill a specific opening he usually has a more or less well defined idea of the kind of man he wants, and that applicant is successful who most closely approximates that ideal. True it is, that one occasionally meets a man who doesn't seem to know what he wants and this is really the easiest type of man to deal with, providing the applicant knows and believes in himself. For the employer's nebulous ideas can often be crystallized into a form according almost exactly with the qualifications of the applicant. Unfortunately most applicants seek merely a certain salary and are ready to take almost any kind of a job which meets this requirement. Hence to a prospective employer applicants appear weak, doubtful of their own capabilities and create a most negative impression. Remember, always, that when a man is hired a contract is made, and a con tract has been well defined as

"a meeting of two or more minds." How then can two minds meet when only one of them has a well defined set of ideas?

The first thing for a man to do is to draw up a detailed list of his qualifications—personal, educational, practical. But let him play fair with himself and note both strong and weak points. Here is a chance to make progress, for ambition will force every normal man to seek remedies as soon as he recognizes his weaknesses. Next, he should whip this detailed list of qualifications into a clear, concise, forceful experience record which will show him up in the best light possible. This is the hardest part of the whole task and will require not an hour, but more often days of hard, consistent effort; but when properly carried out it creates a wonderful feeling of confidence, and gives him a sharply defined idea of his size as pertaining to any job he goes after. As a result he no longer wastes his time and efforts in madly chasing after a wild series of impossible jobs, but settles down to a very determined and much more frequently successful hunt for a job within his capabilities. Incidentally this is an ideal time to take some thought of the future and decide what one would like to be ten or twenty years from now, thus gaining an idea of how far one has progressed along the desired path, and what steps must still be taken to attain the goal. One should of course, set up a high standard, but not an impossible one; and what that may be each man must determine for himself. This mode of procedure enables a man to make a progressive effort to gain a job which is within reason and which will enable him to gain additional valuable experience. He has now reached the point of knowing what he wants, why he wants it and why he should have it. A man in possession of these facts is a hard individual to turn down, and more important still, he has acquired confidence.

Logically, the next step to take, is to find a market for the goods. This is where the Bureau, advertisements, letters and personal tips should be used. But bear in mind, these are media only and none of them will or can get the job itself—they merely put one in touch with it. Most jobs, and particularly the good ones, are "by letter," so it behooves the applicant to give heed to what constitutes a successful letter. To begin with, avoid wasting a paragraph or even a sentence telling how the job was located—the heading does that. Set forth the qualifications in general but forceful terms—the experience record will give the details and proof. Above all be concise, for if you really know—don't think or hope—you will fill the job, your letter will show it. But no man, not a genius can dash off an effective letter in an hour. A successful letter is well worth several hours effort. Even after composing what appears to be a good letter, its value must be tested in the open market—and the first attempt is rarely successful. Persistence plus knowledge and confidence must inevitably gain the day. When seeking a particularly desirable job it is excellent practise to analyze each item of the general experience record and consider its exact bearing on the job in question. Then by re-writing the record, one is in a position to give to each phase of the experience its proper relative degree of prominence, thus creating a much more favorable impression than would be the case were the general record offered.

Finally, comes the interview. Its success will be dependent upon the personal impression, intelligent expression of requirements and qualifications and mutually satisfactory terms. Physical appearance counts for a great deal. Some are naturally gifted, other are not. But one's natural inclinations usually incline one towards a line with which the physical appareance accords. One does not pick a dray horse for the race-track. So look to the neatness of clothes, face and shoes, and let the guest beware of his manners. Watch carefully the questions and answers, for the tongue has often slipped many a man out of a good job. And lastly endeavor to be reasonable in one's demands, for if the employer doesn't use good business judgment in dealing with the employed, the latter will not long have a job. The following summary will supplement the foregoing remarks. It is hoped that both will cause the man who is looking for a job to *think well*, before he acts, and to remember he must act *intelligently* if he is to succeed in his quest.

Summary of Suggestions

1. Decide on what you want.
2. Make sure your qualifications give you an even chance of getting it. But don't think 100 per cent is necessary. Perfection doesn't exist.
3. Don't go after a job unless you mean business.
4. There are three factors to every job, viz.: Advancement, experience, salary. Don't ignore the first two.
5. Remember that the *Job* gets the salary—not the applicant's qualifications.
6. Job-Getting is selling one's services. The successful salesman knows his product thoroughly. Study your goods.

Letter-Writing

1. The object of a letter is to get an interview. Letters don't get jobs.
2. Padding of payrolls is a felony. Padding of letters is equally dangerous for the job-hunter.
3. A letter must arouse interest, create desire, prove the case, convince the reader that an interview will be profitable. Hence: Be as brief as is consistent to prove your claims. Make no claims not backed by the experience record. Always include the experience record.
4. Attractive packages improve the sale of goods. Therefore typewritten letters on plain business stationary are better than long hand ones on club or personal stationary.

Interviews

The interview is "The day in court." Getting it is only half the battle. When being interviewed:

1. Be fully confident of your worth—but not presumptuous.
2. Be sure you want the job and be ready to prove why you should get it.
3. Ask a fair market price for your goods. Don't profiteer. Don't be a philanthropist.
4. Assay the three elements—Advancement—Training—Salary—and be guided by the sum of the three in accepting or declining.
5. Leave in a pleasant hopeful manner if the job is not decided then and there.
6. A letter of acknowledgment of the courtesy of an interview is good policy following a promising call.

Finally

Maintain the proper mental attitude. Don't let your morale slump. Nobody wants a grouch or a man who is not sure of himself.

American Institute of Chemical Engineers

MEETING IN NIAGARA FALLS, JUNE 19-22, 1922

The Summer Meeting of the American Institute of Chemical Engineers will be held at Niagara Falls, June 19-22, with headquarters at the Clifton Hotel. One day will be assigned for a visit to Buffalo to inspect the industries there, and another day will be devoted to a lake trip to Toronto, Canada, and inspection of the chemical plants in that vicinity. The program of papers, on various phases of chemical engineering, will include a symposium on the manufacture and concentration of sulphuric, nitric and hydrochloric acids, as well as phosphoric acid. A number of excellent papers has been promised for this symposium.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

WANTED—PROCEEDINGS OF THE AMERICAN RAILWAY ENGINEERING ASSOCIATION

To complete its files the Engineering Societies Library is in need of the Proceedings of the American Railway Engineering Association for the years 1918, 1919, and 1920. If some member of the Institute has copies of these Proceedings which he is willing to donate to the Library, his action will be greatly appreciated. Address: Mr. Harrison W. Craver, Director, Engineering Societies Library, 33 West 39th Street, New York.

BOOK NOTICES (APRIL 1-30, 1922)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

AUTOMATIC TELEPHONE SYSTEMS.

By William Aitken. Vol. 1. Circuits and apparatus as used in the public services. Lond., Benn Brothers, Ltd., 1921. 282 pp., diagrs., 10 x 8 in., cloth. 25s.

The great mass of detail and the complicated circuit diagrams required to present this subject make special treatment necessary if a treatise is to be suited to the needs of students. This book attempts to present the subject in intelligible form by rearranging the diagrams, eliminating unnecessary crossing lines, simplifying the form and presenting it in such a way as to show the relationship of the system as a whole. To accomplish these ends a large page and a new system of describing the diagrams, which consist in numbering a circuit from end to end with the same system, have been used.

The book covers the whole subject. The principal commercial systems and other less-known systems of promise are described.

CONTINUOUS WAVE WIRELESS TELEGRAPHY.

By B. E. G. Mittell. (Pitman's technical primers.) Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1922. 110 pp., illus., 7 x 4 in., cloth. $0.85.

This little book is offered as an introduction to radiotelegraphy from the engineer's point of view. It avoids the use of mathematics and plunges directly into the subject without a preliminary discourse upon electricity or the development of mechanical analogies. Special attention, so far as space permits, is given to the Pulsen arc and to the construction of tall aerial structures, and useful references to important papers are given throughout the book.

INTRODUCTION TO ELECTRODYNAMICS.

By Leigh Page. Boston and N. Y., Ginn & Co., 1922. 134 pp., 8 x 6 in., cloth. $2.00.

The object of this book is to present a logical development of electromagnetic theory founded upon the principleof relativity. So far as the author is aware, the universal procedure has been to base the electrodynamic equations on the experiments of Coulomb, Ampere and Faraday, even books on the principle of relativity going no farther than to show that these equations are covariant for the Lorentz-Einstein transformation. As the dependence of electromagnetism on the relativity principle is more intimate than this covariance suggests, he believes it more logical to derive the electromagnetic equations directly from this principle.

The book covers topics appropriate for a one-year graduate course in electrodynamics and electromagnetic theory of light. It should interest those who are looking for a logical rather than a historical account of the science.

PRINCIPLES OF ELECTRICAL ENGINEERING.

By William H. Timbie and Vannevar Bush. N. Y., John Wiley & Sons, Inc.; Lond, Chapman & Hall Ltd., 1922. 513 pp., illus., 8 x 5 in., cloth. $4.00.

This text-book written for students of college grade, with a knowledge of calculus and physics, aims to provide a substantial first course in the subject which will present rigorously, yet in understandable form, the basic principles underlying modern electrical engineering, to be followed by detailed courses in direct and alternating-current machinery. Special features are the stressing of the subject of the magnetic circuit; the use of the electron theory as a basis for explanation; the inclusion of the subjects of thermionic emission, conduction through gases, electrolytic conduction and high-frequency phenomena; a novel approach to the subject of the behavior of dielectrics and numerous live problems.

PRINCIPLES OF MECHANICAL REFRIGERATION.

By H. J. Macintire. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1922. 252 pp., illus., diagrs., 8 x 6 in., cloth. $2.50.

Based on a study course of twenty articles published in *Power* during 1920. The book is intended to cover the entire field of refrigeration in an elementary manner, with little use of mathematics. Analogies to steam machinery and steam cycles are used to explain the action of refrigeration.

ESSAI D'OPTIQUE SUR LA GRADATION DE LA LUMIERE.

By Pierre Bouguer. Paris, Gauthier-Villars et Cie, 1921. (Les maîtres de la pensee scientifique.) 129 pp., 7 x 5 in., paper. 3 fr.

This classic of literature of optics is an account of Bouguer's study of certain important optical problems connected with the radiation of light and its absorption by various substances. It is the work which first set forth the basis of photometry, and led to the invention of the photometer by the author in 1748.

The present edition reproduces the original text of 1729.

METRIC SYSTEM FOR ENGINEERS.

By Charles B. Clapham. N. Y., E. P. Dutton & Co., 1922. (Directly-useful technical series.) 181 pp., 9 x 6 in., cloth. $6.00.

This book is not concerned with the controversy regarding the metric system. Its object is to give a full practical explanation of the system as it is met in engineering calculation and measurement, for use by draftsmen, mechanics and engineers.

After an introduction explaining basic principles, the simple measures of length, area, volume, capacity and weight are discussed, with special attention to the usual measuring tools found in workshops and drafting rooms. Compound measures used in engineering are then described, with the derivation of the corresponding British equivalents. Succeeding chapters give tables of the commoner engineering constants in British and metric units, and examples of the alteration of numerical constants in formulas when metric values are to be used.

ORGANIC CHEMISTRY.

By Victor von Richter. Vol. 2. Chemistry of the carbocyclic compounds. Phila., P. Blakiston's Sons & Co., 1922. 760 pp., 9 x 6 in., cloth. $8.00.

After an interval of six years since the appearance of volume one, the second volume of this translation, dealing with carbocyclic or closed carbon chain compounds, is now available. The translation follows the 11th German edition, prepared in 1912.

The outstanding feature of this work is the large number of compounds listed, with outlines of the methods for preparing them and accounts of their important properties. No other book of its size gives such an exhaustive list. Because of this comprehensiveness, the book is most useful for references, particularly when the large encyclopedias are not accessible.

ANALYSIS OF FUEL, GAS, WATER AND LUBRICANTS.

By S. W. Parr. Third edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1922. 250 pp., illus., diagrs., tables, 8 x 6 in., cloth. $2.50.

This book was originally published for use by students of mechanical engineering and provided a course intended to help the engineer to a better understanding of the literature of the topics treated, and also to an appreciation and more intelligent use of data supplied by the chemist.

The present edition has been expanded to meet the needs of students of chemistry as well. It contains a synopsis of the author's lectures on fuel, gas, water and lubricants, and a course in laboratory methods for their analysis.

WELL-BORING FOR WATER, BRINE AND OIL.

By C. Isler. Third edition. Lond., E. & F. N. Spon, Ltd.; N. Y., Spon & Chamberlain, 1921. 259 pp., illus., diagrs., 9 x 6 in., cloth. $4.80.

Describes various methods of boring and drilling in search of water, brine, oil or minerals, including driven and bored tube wells, the Kind-Chaudron, Dru and Mather & Platt deep-boring systems; the American rope-boring system and diamond drilling. Methods of raising water are dealt with. This edition is revised and includes the methods developed during recent years.

DESIGN AND CONSTRUCTION OF OIL ENGINES.

By A. H. Goldingham. Fifth edition. N. Y., Spon & Chamberlain; Lond., E. & F. N. Spon, 1922. 2 pt. in 1 vol., illus., diagrs., 8 x 5 in., cloth. $4.00.

This treatise comprises two parts. The first is entirely new. It contains 141 pages devoted to high compression oil engines, including solid injection, air blast and modern two-cycle engines. The design and construction of the parts of these engines, testing installation and construction are considered, and the leading American and English designs are discussed. The second part relates to earlier types of low compression oil engines. It is apparently a reprint of edition four of the work, with the omission of the appendix on Diesel engines, now included in a separate treatise on that subject.

MECHANICAL STOKERS.

By Joseph G. Worker and Thomas A Peebles. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1922. 258 pp., illus., tables, diagrs., 9 x 6 in., cloth. $3.00.

Although stokers are treated in books on boilers and power plant equipment, there has been no work treating the stokers as a separate unit until the appearance of the present volume. It treats the phenomena of combustion in relation to stokers, describes mechanical stokers and modern practise in stoker installation and use and discusses the selection of stokers for different fuels and differing conditions. The authors have endeavored to give reliable unbiassed opinions and facts from field experience in design, installation and operation.

CRAIN'S MARKET DATA BOOK AND DIRECTORY OF CLASS, TRADE AND TECHNICAL PUBLICATIONS.

Second edition 1922. Chicago, G. D. Crain, Jr. 456 pp., 9 x 6 in., cloth. $5.00.

This is a reference book for advertisers. An account of trade, industry and profession is given which presents the statistical and marketing data necessary to give the advertiser or merchant a picture of the field as a whole. Each account is supplemented by a full list of American trade journals devoted to that industry, with their addresses, circulation, advertising rates, etc. A list of important foreign trade journals is included.

PULLING TOGETHER.

By John T. Broderick. Schenectady, N. Y., Robson & Adee, 1922. 141 pp., 8 x 5 in., cloth. $1.00.

A discussion of current problems connected with the relations of capital and labor, with employee representation as the central theme. Dr. Steinmetz has contributed a brief introduction.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Baltimore.—April 21, 1922, Engineers Club. Subjects: "Radio Telephony and Broadcasting" by Mr. L. W. Chubb, of the Westinghouse Electric and Manufacturing Company; and "High-Power Transoceanic Radio Telegraphy" by Mr. E. F. W. Alexanderson, of the Radio Corporation of America. Attendance 225.

Boston.—April 11, 1922, Auditorium, Engineers Club. Subject: "Signal Devices Used in Warfare" (illustrated by lantern slides). Speaker: Mr. H. J. W. Fay, of the Submarine Signal Company. Attendance 125.

May 9, 1922, Franklin Union Hall, Boston. Election of officers as follows: Chairman, Edward L. Moreland; Vice Chairman, Alexander Macomber; Treasurer, Ira N. Cushing; Secretary, F. S. Dellenbaugh, Jr. Subject: "Fifty Years of Physics." Speaker: Professor Arthur Gordon Webster, of Clark University, Worcester. Attendance 260.

Cleveland.—April 18, 1922, Electrical League Rooms. Mr. N. W. Storer, vice-president, was the guest of the Section and made a few remarks relative to the work of the Institute, before the presentation of the paper of the evening. Paper presented: "Automatic Substations." Speaker: Mr. L. D. Bale, of the Cleveland Railway Company. After the meeting special cars were provided through the courtesy of the Cleveland Railway Company, and a trip was made to E. 99th Street automatic Substation, where the various pieces of equipment were explained. Attendance 155.

Columbus.—April 27, 1922, Engineers' Club. Organization meeting. Election of temporary officers; appointment of committees. Attendance 13.

Connecticut.—April 18, 1922, Hotel Elton, Waterbury, Conn. A banquet preceded the meeting. Subject: "Electric Furnaces in the Brass Industry." Speaker: Dr. H. W. Gillette, of the Bureau of Mines. Attendance 180.

Denver.—April 14, 1922, Adams Hotel. Joint meeting with Colorado Section of the A. I. M. & M. E. Subject: "A Process for the Reduction of Zinc Ore and Complex Ores Containing Zinc by Electrothermic Dry Distillation" (illustrated by lantern slides). Speaker: Dr. Charles H. Fulton, Director, School of Mine and Metallurgy, University of Missouri. Attendance 110.

May 5, 1922, University of Colorado. General engineering meeting held under the auspices of the Denver Section, but participated in by Colorado Engineering Council and the nine constituent member societies. Meeting called to order at 4:00 p. m. Election of officers as follows: Chairman, H. B. Barnes, Vice-Chairman, H. B. Dwight; Secretary-Treasurer, R. B. Bonney. The audience was then entertained by three selections of music, transmitted from Denver, a distance of thirty miles,

by radio. Subjects presented at meeting: "The Commercial Aspect of Research Work" by Mr. L. T. Robinson, of the General Electric Company, Schenectady; and "Electron at Work" by Dr. Willis R. Whitney. The visitors were entertained at Dinner by the University. After dinner the engineering students held open house throughout the engineering buildings and the guests were shown through all departments. Attendance 300.

Detroit-Ann Arbor.—March 10, 1922, Detroit Edison Building. Subject: "The Economic Loading of Transformers." Speaker: Mr. P. O. Reyneau, of the Detroit Edison Company. Attendance 118.

April 28, 1922, Detroit Edison Company. Subject: "The Electrification of the Transcontinental Line of the Chicago, Milwaukee and St. Paul Railway" (illustrated by motion pictures and lantern slides.) Speaker: Mr. J. A. Anderson, Superintendent of Shops at Milwaukee Locomotive Plant of the Chicago, Milwaukee and St. Paul Railroad. Attendance 160.

Fort Wayne.—April 20, 1922, Duemling Clinic. Dr. C. C. Grandy, a member of the Duemling Clinic, the speaker of the evening, explained X-ray from a radiographic, fluoroscopic and therapeutic standpoint and illustrated his lecture by slides with the assistance of Dr. V. Hilgeman. At the completion of the meeting Doctors Grandy, Duemling and Hilgeman escorted the guests through the Clinic showing the performance of all appliances. Lunch was served by Dr. Duemling. Attendance 89.

Indianapolis-Lafayette.—May 5, 1922, Chamber of Commerce. Subject: "The Economic Aspect of Long-Distance Power Transmission." Speaker: Professor Alfred Still, Purdue University. Attendance 42.

Ithaca.—April 28, 1922, Sibley Dome. Subject: "The Superpower System." Speaker: Mr. W. S. Murray. Attendance 550.

May 5, 1922, Franklin Hall. Subject: "Electrification of C. M. & St. Paul Railway." Speaker: Mr. L. J. Murray. Attendance 200.

Kansas City.—April 28, 1922, University Club. The "Developments in Wireless Telephony" a Westinghouse Electric & Manufacturing Company paper, was read by Mr. H. C. Thompson, an engineer from the St. Louis office of the company. The paper was illustrated with slides showing typical installations and the general theory of operation. Attendance 40.

Lehigh Valley.—March 9, 1922, Pardee Hall, Lafayette College, Easton, Pa. Preceding the meeting an informal dinner was held at the Easton Y. M. C. A., with Mr. N. W. Storer, a vice-president of the Institute, and Mr. C. W. Horn, speaker of the evening as guests of honor. Subject: "Radio Telephony and Broadcasting." Speaker: Mr. C. W. Horn, of the Westinghouse Electric & Manufacturing Company, E. Pittsburgh. The paper was accompanied by interesting demonstrations and by means of loud speaking attachment, the audience was entertained with speeches, music and singing picked up from the nearest broadcasting stations within the range of Easton. Attendance 350.

Lynn.—April 12, 1922. Subject: "Earthquakes and Seismographs." Speaker: Professor, J. B. Woodworth, Chairman of the Department of Geology, Harvard University. The lecture was illustrated by a number of lantern slides. Attendance 130.

April 26, 1922. Subject: "The Caribou Hydroelectric Development of the Great Western Power Company, California" (illustrated by colored slides and moving pictures). Speaker: Mr. Albert A. Northrop, of the Stone & Webster Corporation, Boston. Attendance 250.

May 9, 1922, Classical High School, Lynn. Ladies' Night. Election of officers as follows: Chairman, J. W. West; Vice-Chairman, L. E. Smith; Secretary-Treasurer, W. M. Howe; Assistant Secretary, Paul E. Twiss. Subject: "Old New England Gardens." Speaker: Mr. Loring Underwood, of Boston. Attendance 600.

Milwaukee.—April 27, 1922, City Club of Milwaukee. Annual Dinner. Subject: "Radio Telephony." Mr. F. A. Kartak, head of the Electrical Engineering Department of Marquette University, presented the principal paper. Addresses were also made by Mr. A. W. Berresford, Past-president of the A. I. E. E., and by the Reverend J. B. Kremer, Professor of Physics at Marquette University. During the course of the dinner the radio equipment of the City Club was in operation and music which was being broadcast in Milwaukee was received. However, due to static conditions no long-distance broadcasting could be picked up. Attendance 180.

Minnesota.—April 24, 1922, University of Minnesota. Subject: "The Electrification of the Transcontinental Line of the Chicago, Milwaukee and St. Paul Railroad—Intimate Details of Installation and Construction." Speaker: Mr. A. B. Baker, of Chicago. The lecture was illustrated with 2000 feet of film and numerous slides showing features of construction and beautiful scenic views. Attendance 410.

Philadelphia.—April 10, 1922, Engineers' Club. Informal dinner preceding meeting. Subject: "Flux and Current." Speaker: Dr. Harold Pender, of the University of Pennsylvania. Attendance 139.

May 8, 1922, Engineers' Club. Preceding the meeting an informal dinner was served to the delegates to the meeting of the Executive Committee of the Second Geographical District and to the speaker of the evening. Subject: "The Coming of the Alternating Current." Speaker: Mr. B. G. Lamme, Chief Engineer, Westinghouse Electric & Manufacturing Company. Attendance 120.

Pittsburgh.—April 18, 1922, Chamber of Commerce Building. Joint meeting with local Section of A. I. M. E. Subject: "Central Station Power for Coal Mines." Speaker: Mr. J. C. Damon, of the West Penn Power Company. Mr. W. A. Affelder, of the Hillman Coal & Coke Company, led the discussion, followed by Messrs. Nelms, Fear, Gibbs and Stone. Attendance 105.

Portland.—April 26, 1922. Public Library. "Demonstration of Telephone Operating Methods" by the Pacific Telephone and Telegraph Company, including a lecture by Mr. A. E. Burns on "Some Fundamental Features of Machine Switching (Automatic)." A reel of motion pictures taken in the Portland telephone offices was shown. The demonstration was followed by several high-class vocal and instrumental musical numbers. Attendance 145.

Providence.—April 18, 1922, Providence Engineering Society Rooms. Joint meeting of the Providence Engineering Society and the Providence Section A. I. E. E. Subject: "Practical Economics and Its Relation to the Engineer." Speaker: Mr. James M. Matthews, Director of the Division of Practical Economics, Babson Institute. Attendance 75.

May 5, 1922, Providence Engineering Society Rooms. Election of officers as follows: Chairman, Robert W. Adams; Vice-Chairman, Howard A. Stanley; Secretary-Treasurer, F. N. Tompkins. Subject: "The Commercial Importance or Aspects of the Transformer in Present Day Life." Speaker: Mr. Matthew O. Troy, of the General Electric Company, Pittsfield, Mass. Attendance 35.

St. Louis.—April 26, 1922, Engineers' Club. Dr. William McClellan, President of the A. I. E. E., talked on topics of a general nature, principally regarding economic conditions, and pointed out some of the things which he thought would be necessary in order for America and the electrical industries to enjoy the greatest prosperity. Attendance 96.

San Francisco.—March 24, 1922, Engineers' Club. Subject: "Engineering Short Cuts as Applied to Power Circuit Studies." Speaker: Mr. A. W. Copley, of the Westinghouse Electric & Manufacturing Company. Attendance 40.

Schenectady.—April 21, 1922, Edison Club Hall. Subject: "Radio Transmission." Speaker: Mr. W. R. G. Baker, of the

General Electric Company. The first part of the program consisted of a wireless concert by W. G. Y. broadcasting station of the General Electric Company. Mr. Stein, Radio Engineer of the General Electric Company, gave a brief resume of the history of wireless transmission. Attendance 250.

May 9, 1922, Edison Club Hall. Joint meeting with American Chemical Society, Society of Engineers of Eastern New York, American Society of Mechanical Engineers, and American Welding Society. Subject: "Activities of the American Engineering Societies." Speaker: Dean M. E. Cooley, President, Federated American Engineering Societies; Dean, College of Engineering, University of Michigan. Attendance 90.

Syracuse.—April 28, 1922, Assembly Hall, Onondaga County Court House. Subject: "The Automatic Telephone." Speaker: Mr. Arthur Bessey Smith, of the Automatic Telephone Company. Attendance 30.

Toledo.—April 21, 1922. Election of officers as follows: Chairman, Gilbert Southern; Vice-Chairman, Ira B. Matthews; Secretary-Treasurer, Max Neuber. Attendance 10.

Toronto.—April 21, 1922, Mining Building, Toronto University. Annual Business Meeting and Election of officers as follows: Chairman, S. E. M. Henderson; Secretary, D. B. Fleming; Executive Committee, Messrs. W. L. Amos, O. V. Anderson, L. B. Chubbuck, C. H. Hopper, S. L. B. Lines, C. E. Schwenger. Subject: "Rocky Mountain Trails to Mount Robson." Speaker: Professor A. P. Coleman. The lecture was illustrated by slides from Professor Coleman's photographs and colored by himself to correspond with his own notes. Attendance 100.

Urbana.—May 3, 1922. Election of officers as follows: Chairman, H. A. Brown; Secretary, E. B. Paine. Symposium on "Modern American and European Power Plant Practise." Speakers: Professors E. B. Paine and Morgan Brooks, and Mr. G. S. Parker. Attendance 28.

Utah.—April 28, 1922, Gold Room, Commercial Club. Subjects: "The Manufacture of Dielectric Porcelain" by Mr. A. M. Jackson, of the Locke Insulator Corporation; and "First Aid and Resuscitation from Electric Shock by Dr. E. L. Skidmore. Attendance 65.

Worcester.—April 27, 1922, E. E. Bldg., W. P. I. Subject: "The New Conservation." Speaker: Mr. F. M. Feiker, Vice-President of the McGraw-Hill Company, New York. Attendance 32.

PAST BRANCH MEETINGS

Armour Institute of Technology.—April 21, 1922. Joint meeting with Armour Architectural Society and Western Society of Engineers. Subject: "Ethics." Speaker: Mr. Emery Stanford Hall. Architectural Engineer. Attendance 162.

Brooklyn Polytechnic Institute.—May 4, 1922. Joint meeting with A. S. M. E. and A. S. C. E. Branches. Mr. Williams, engineer of the Chicago, Milwaukee and St. Paul Railroad, delivered a very interesting lecture, illustrated by slides and motion pictures. Attendance 200.

University of California.—April 19, 1922. Subject: Acquirement of Water Rights for Power Development." Speaker: Professor S. T. Harding. Attendance 18.

Carnegie Institute of Technology.—May 9, 1922. Subject: "Electrification of the Chicago, Milwaukee and St. Paul Railroad" (illustrated by slides and moving pictures). Speaker: Mr. L. J. Murray. Attendance 250.

University of Cincinnati.—March 27, 1922. Subject: "Automatic Substations and Some of the Results of Tests on Them." Speaker: Mr. H. E. Deardoff, E. E. '22. Attendance 45.

April 10, 1922. Subject: "The Relation of Geology to Engineering." Speaker: Professor N. M. Fenneman. Attendance 46.

April 17, 1922. Subject: "The Trend of Modern Engineering." Speaker: Professor A. M. Wilson. Attendance 45.

April 24, 1922. Subject: "Oil Circuit Breakers and Some of Their Characteristics." Speaker: Mr. G. M. Arnold, E. E. '22. Attendance 27.

Colorado State Agricultural College.—May 1, 1922. Students were entertained by Professor E. B. Dale, who tuned in on the news items, stock and weather reports, and music from The Reynolds Radio Company near Denver. Attendance 20.

Iowa State College.—April 12, 1922. Subject: "The Electrification of the Chicago, Milwaukee & St. Paul Railway" (illustrated). Speaker: Mr. F. E. Sheddon. The lecture was followed by two reels of moving pictures entitled "A Ride Over the Great Divide." Attendance 250.

April 26, 1922. Subject: "Poles from Forest to Transmission Line" (illustrated). Speaker: Mr. S. G. Harris, of the Page & Hill Company, Minneapolis. Attendance 65.

Kansas State College.—April 24, 1922. Election of officers as follows: Chairman, L. O. Sinderson; Vice-Chairman, Lester Means; Corresponding Secretary, K. C. Frank; Recording Secretary, A. Jennings. Subjects: "Your Bosses" by Charles Efenstine; "Lucifern's Perpetual Light" by Harvey Staif; "Electrification of the New York, New Haven, and Hartford Railroad" by L. O. Sinderson. Attendance 67.

University of Kansas.—March 30, 1922. Informal talks were given by Mr. R. I. Parker, General Electric Company's Chicago representative, and Mr. Pfeif, General Electric Company, Schenectady, N. Y. Attendance 45.

April 1922. Joint meeting with local Branches of A. S. M. E. and A. S. C. E. Mr. Harry Hunter, of the Herrington, Howard & Ash Engineering Company of Kansas City, gave an illustrated talk on Russia. Attendance 34.

Lafayette College.—March 30, 1922. Subjects: "History, Construction and Uses of the Electric Furnace" by Lester J. McMackin; "Uses of A-C. Motors on High Speed Elevators" by Leonard Spaulding. Attendance 16.

April 6, 1922. Inspection trip to William Wharton Jr. Foundry and Machine Shops at West Ward, Easton, Pa. There the electric furnace was explained by the engineer in charge; the whole power system of the works was looked at. Attendance 16.

April 20, 1922. Subjects: "Description of the Delaware River Plant of the Philadelphia Electric Company," by Mr. George A. Moore; and "Electricity on the Automobile," by Fred L. Suttle. Attendance 16.

April 27, 1922. Subject: "Electron as Applied to Wireless Telephony." Speaker: Mr. Donald Roseberry. Attendance 16.

University of Maine.—April 26, 1922. Subject: "The Design of Electrical Machinery." Speaker: Professor Hill. Attendance 16.

University of Michigan.—May 3, 1922. Election of officers as follows: Chairman, R. N. Olds; Vice-Chairman, C. C. Farnam Secretary, A. J. Martin; Treasurer, Ray Van Volkenburg. Attendance 22.

University of Minnesota.—April 24, 1922. Joint meeting of the Minnesota Section and the University of Minnesota Branch. Subject: "The Electrification of the Chicago, Milwaukee and St. Paul Railroad." Speaker: Mr. A. B. Baker. The lecture was illustrated with slides and films. Attendance 350.

May 3, 1922. Subject: "The Northern States Power System," Speaker: Mr. Whiton, of the Northern States Power Company. Attendance 21.

University of Nebraska.—April 13, 1922. Subject: "Public Relations." Speaker: Mr. Horace M. Davis, Secretary Nebraska Section, N. E. L. A. Refreshments were served. Attendance 50.

University of North Carolina.—May 4, 1922. Subjects: "The Reaction Turbine" by Mr. C. G. Mauney; "Development of Radio Telephony" by Mr. J. L. Pressley. Attendance 34.

University of North Dakota.—April 10, 1922. Subject: "How Engineers Celebrate at Other Colleges." Speaker: Mr. Albert W. Cook. Attendance 21.

Oklahoma A. & M. College.—April 18, 1922. Subject: "Engineering as a Profession." Speaker: Professor W. J. Miller. Attendance 28.

April 24, 1922. Open meeting. The following films, furnished by courtesy of the General Electric Company, were shown: three reels "The King of the Rails"; two reels "The Panama Canal"; one reel "The Electrical Giant"; one reel "Microscopic Views of Asphalt." Attendance 350.

May 1, 1922. Open meeting. Subject: "The Electrification of the Transcontinental Line of the Chicago, Milwaukee and St. Paul Railway— Intimate Details of Installation and Construction" (illustrated). Speaker: Mr. F. R. Sheeden. Attendance 800.

Rutgers College.—April 20, 1922. Subjects: "The Use of Imaginary Numbers in the Solution of Alternating-Current Problems" by T. P. Brown, '22; and "A Short History of Electric Traction" by Professor F. F. Thompson. Attendance 10.

May 11, 1922. Election of officers as follows: Chairman, C. S. Beattie; vice-chairman, J. Glatzel; Secretary-Treasurer, E. H. Erickson; recording Secretary, H. F. Scarr. Talk by Professor F. C. Van Dyck, on his experiences during fifty years at Rutgers. The talk was followed by a smoker and refreshments. Attendance 31.

University of Southern California.—April 19, 1922. Subject: "The Relation of Physics to Modern Engineering." Speaker: Dr. J. A. Anderson, of the Mount Wilson Observatory, California. Attendance 12.

Virginia Military Institute.—April 27, 1922. Combined meeting of all engineering societies. Subject: "Asphalt and Its Uses in Engineering." Speaker: Mr. Rosengarten, of New York. Attendance 200.

May 1, 1922. Subject: "The Operation of a Large Industrial Plant in which Electricity is Used." Speaker: Mr. W. P. Venable. Attendance 61.

University of Virginia.—April 12, 1922. Subjects: "The Vacuum Tube" (illustrated), by Mr. John Mills, of the Western Electric Company; "Sanford Riley Stokers" (illustrated), by Mr. W. M. Smith, "Westinghouse Steam Turbine" (illustrated), by Mr. W. N. Brown. A Westinghouse picture "The Romance of Rails and Power" was shown. Attendance 125.

University of Washington.—May 2, 1922. Subject: "The Telechrometer." Speaker: Major Garrison Babcock, President of the Seattle Chapter of the American Association of Engineers. Several photographs and a model were shown. Attendance 20.

West Virginia University.—April 24, 1922. Subjects: "Vacuum Tubes for Amplification" by A. C. Price; "Electrification of Railroads" by Fitzhugh Donnelly; "Invention of the Telephone" by C. D. Ernest; "Comparative Cognitive Reaction-Time" by R. Mendelsohn. Attendance 22.

May 8, 1922. Subjects: "Principles of Rate Making" by R. K. Parks; "Development of Electric Railways" by H. Chandler; "Sale of Service by Practising Engineers" by A. F. Richards; "Hydroelectric System of Ontario" by J. R. Richards; "Selection of Apparatus for Electric Cranes" by C. C. Cantner; "Power Distribution by Aerial Cables" by C. Snyder; "Industrial Lighting" by L. T. Faulkner; "Interconnection of Central Stations" by G. A. Moffet. Attendance 25.

University of Wisconsin.—May 3, 1922. Subject: "Chicago, Milwaukee and St. Paul Railroad Electrification." Speaker: Mr. E. M. Lunda. Attendance 17.

Yale University.—April 2, 1922. Second of a series of talks on "Psychology" by Professor Angier, of the Psychology Department, and Dean of Freshmen, Yale University. Attendance 50.

April 9, 1922. Third and last of a series of talks on "Psychology" by Professor Angier. Attendance 50.

April 10, 1922. Subject: "Electrochemistry." Speaker: Professor L. B. Johnston, of the Department of Chemistry, Yale University. Attendance 12.

April 21, 1922. Meeting held under auspices of Yale Branch for the benefit of those attending a short course for electric metermen at the University. Subject: "Will the Electric Utility Business Grow." Speaker: Mr. M. H. Aylesworth, Executive Manager, N. E. L. A., New York. Attendance 75.

April 25, 1922. Subject: "Psychology and the Engineer." Speaker: Professor R. P. Angier. Attendance 100.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the Societies constituting the Federated American Engineering Societies, and* ***not*** *to the A. I. E. E.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE, as above.***

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

OPPORTUNITIES

LARGE MANUFACTURER OF MAGNET CONTROLLERS has opening for engineer who is familiar with design and application of a-c. and d-c. magnet controllers. Position requires man who has had considerable experience in this line of work and who is capable of taking charge of the development of a line of contractors and controllers for special application. Liberal salary. Location New York City. V-444.

YOUNG SALESMAN for electric motors, should be member A. I. E. E. Selling ability first, not 1921 graduate. Contractor's knowledge desirable. Application by letter. Location, New York City. V-505.

DESIGNERS of electrical switching apparatus, oil circuit breakers, carbon circuit breakers and outdoor switching devices. Graduate of good technical school preferred. Application by letter stating age, experience and salary expected. Location, Pittsburgh, Pa. V-514.

ERECTING ELECTRICAL INSPECTOR to handle work on the Pacific Coast. Will be located in either Seattle or San Francisco. Must be located in this vicinity. Positions also open in Pittsburgh, Louisiana, Georgia and St. Louis. Application by letter. Salary not stated. V-548.

INSTRUCTOR in engineering drawing, year beginning October 1. Young technical graduate with drafting room experience. Application by letter. Location, Ohio. V-549.

ENGINEER with extensive design experience on fittings for overhead catenary line construction

and transmission lines. In replying, state age, experience and salary expected. Location, Pittsburgh, Pa. V-557.

ENGINEER who has had considerable experience in designing and building special forging machines or heavy duty machines. Application by letter. Salary not stated. Location, Atlanta, Ga. V-613.

RESEARCH ENGINEER. Attractive position with exceptional opportunities for future open to man having right qualifications. Requires ability to apply sound scientific principles and reasoning to analysis and solution of wide variety of general technical problems demanding fundamental research. Problems are mainly in general field of mechanical engineering, although many are typical problems of physics and chemistry, some requiring special mathematical ability. Applicants should have not less than five years active experience in research along lines indicated above. Should have advanced scientific as well as engineering training, with special regard to fundamentals rather than to details of engineering practise. Such courses of instruction for instance, as lead to advanced degrees in physics, chemistry and mathematics, with special reference to mechanics and thermodynamics are of much importance. Equally important is sound knowledge of practical engineering problems and appreciation of various factors which must be considered in applying scientific analysis to these problems. Applicant should state particularly lines of engineering with which he is familiar and extent of acquaintance with other engineers in these lines. Ability to summarize scientific and technical papers and to write up technical material for publication is of importance, as is ability to maintain cordial relations with other engineers engaged in similar lines of work. Application by letter. State when available and salary. Location, New York City. V-629.

INSTRUCTORS (2) for term beginning next September for department of Physics. Work will consist in total of not more than fourteen hours weekly with recitation and laboratory sections in elementary physics. Possession of a doctor's degree by candidates is not absolutely essential but it is desired to find men who are interested in physics and who may be counted upon to go forward in their studies. Every encouragement in the way of arrangement of schedule of hours and in securing facilities for research will be given. Application by letter. Location, New York City. V-637.

TIME STUDY EXPERT for job analysis and production control. Application by letter. Salary not stated. Location Des Moines, Ia. V-654.

ENGINEER, high grade, familiar in manufacture of wireless sets, knowing costs, etc. Right man can create his own opportunity. Application by letter Salary not stated. Location, New York City. V-672.

SALESMAN to sell wiring contracts and electric fixtures. Should have some knowledge of the contracting business. Location, New York City. Commission only. Application in person. V-681.

RADIO RESEARCH ENGINEERS AND PHYSICISTS. University or commercial radio research experience. Must be able to plan and carry out independent experimental investigations in field of short and long-distance wave transmission, radiotelephone receivers and transmitters, and kindred subjects. Write, including references to publications, experience, salary desired and time of availability. Application by letter. Salary not stated. Location, New York City. V-681.

SALESMAN to sell electric tools, Wallace planers, jointers, saws, etc; also Van Dorn electric tools. An excellent line of goods and good chance to earn. Application in person. Commission basis. Location, New York City. V-795.

ELECTRICAL ENGINEERING GRADUATE, with experience in testing, to plan and supervise test work and analyze results thereof. Good opportunity for ambitious young man. Application by letter. Location Yonkers, N. Y. V-825.

SALESMAN to handle asbestos products, especially pipe covering. Knowledge of contracting and sales experience necessary. Application by letter. Salary and commission. Location, New Jersey. V-831.

EXPERIENCED SALESMAN to handle the sale of a line of quality dial gages. Should have experience and acquaintance among users of this product. Application by letter. Salary not stated. Headquarters, New York City. V-837.

SALESMAN to sell machinery or electrical tool equipment. Application in person. Salary not stated. Headquarters, New York City. V-838.

ENGINEER who has had some familiarity with heavy steel material (not structural steel) such as banks and heavy chemical equipment, from construction and sales standpoint. Application by letter. Headquarters, New York City. V-842.

ELECTRICAL ENGINEER who has had actual practical experience in the construction of electric cooking and heating apparatus from both designing standpoint as well as manufacturing standpoint. Application by letter. State salary expected and give full details with reference to experience. Location, Ohio. V-855.

GENERAL INSPECTOR for company manufacturing gold-filled watch cases. Experience in this line absolutely essential. Application by letter only. Salary not stated. Location, Ohio. V-856.

ELECTRICAL ENGINEER. With experience on transformer design. Splendid opportunity. Application by letter stating age, education and practical experience. Location, Pa. V-867.

RADIO SALESMAN (4 or 5). Application in person. Commission basis. Headquarters, New York City. V-869.

ESTIMATOR for plumbing and heating. One who can talk to builders, estimate and get business. Must understand the plumbing and heating business. Application by letter. Salary not stated. Location, New York City. V-871.

ELECTRICAL DRAFTSMAN. Must be experienced on power house and substation work. Will not consider anyone who has not had this experience. Application in person. Salary not stated. Location, Brooklyn, N. Y. V-873.

SALES ENGINEER familiar with officials of public utility, properties, particularly those in New York City. V-881.

ENGINEER familiar with magnesium and magnesium alloys, their properties, applications and market. Man with some salesman experience preferred. Headquarters, New York City. Application in person. Permanent connections and attractive terms for right man. V-883.

PIPE COVERING ESTIMATOR. Must have actual experience on the various types of heating and ventilating systems. Application by letter. Salary not stated. Location, New York City. V-904.

ESTIMATORS. Trained salesman to follow up architects and builders in and about New York City and obtain contracts for electrical construction; also follow up industrial establishments for orders for yearly maintenance and repair of electrical machinery and elevators. Opportunity for able man to become essential part of established concern. Commissions, drawing account and bonus. Application by letter. Headquarters, New York City. V-913.

SALES ENGINEERS for company manufacturing stokers for New York City, South Ohio with headquarters in either Columbus or Cincinnati, and St. Louis. Proposition with exception of New York is straight commission one with drawing account commensurate with amount of business being closed by the men, although in New York City, we desire a man either on commission or on salary and bonus arrangement. Should be thoroughly posted in combustion work and well acquainted in their respective fields with power plants and various engineering offices, etc. Application by letter. Headquarters, Boston, Mass. V-917.

MECHANICAL or ELECTRICAL ENGINEER with some operating experience. Should have a thorough knowledge of physics, especially thermodynamics. Experience in operation and design of temperature and pressure instruments and flow meters is essential. Work in instruments control departments covers design and control of a large variety of instruments used in manufacture of automobile tires. Most of work is laboratory. Application by letter. Salary not stated. Location, Ohio. V-924.

ENGINEER with experience in designing switchboards and men who have experience in diagram work in connection with the layout of power houses and substations. Application by letter. Salary not stated. Location, Pa. V-954.

YOUNG ENGINEER for experimental work, to write reports, descriptions, etc. Recent graduate considered. Application by letter. Location, New York. V-957.

ELECTRICAL REPAIR MAN and TROUBLE SHOOTER. Should be graduate E. E. Must know Spanish. Single man preferred. Position will lead to foreman of repair shop. Application by letter. Salary not stated. Location, Chile. V-982.

FOREMAN of "Inst. Laboratory." Position requires man with thorough knowledge of electrical indicating instruments both portable and station type, such as wattmeters, voltmeters, ammeters, etc. Prefer technical graduate or man who has had previous practical experience along this line, which would be equivalent to technical education. Application by letter. Salary not stated. Location, New Jersey. V-993.

ENGINEER with 10-15 years experience in elevator business, man with sufficient presence and ability to meet leading engineers in building industry and assist them in calculating size, number, speed and load of elevators for any particular building. Application by letter. Salary not stated. Location, Pa. V-994.

ENGINEERS electrical, mechanical, railroad, interested in electrification of Siberian industries and railways. Application by letter giving age, experience, and reference. Location, Siberia. V-997.

SALES ENGINEERS, chemical or mechanical. Several engineers to handle state territories on liberal commission basis. Company manufactures alloy combining unusual wearing qualities as a bearing metal, remarkable acid resistance, and great strength. Castings are made from 15 to 60 scleroscope, and from 75,000 to 100,000 pounds per square inch tensile strength. This metal has been on the market for eight years and is widely used by many nationally known concerns. An automobile valve, made of this alloy, is meeting with instant success wherever it has been introduced. The sales rights for this valve will be given along with other lines and will show a profit from the start. Applicants should state age, education, experience in detail, and choice of localities. Recent photograph desirable. Headquarters, Wisconsin. V-1001.

SALES MANAGER for roofing department, to take care of office correspondence. Preferably one who knows New England territory and something of building construction and merchandizing. Application in person. Salary not stated. Location, Boston. Headquarters, New York City. V-1007.

ENGINEER with thorough knowledge of passenger traffic routing on railroads. Application in person. Salary not stated. Location, New York City. V-1013.

GRADUATE ELECTRICAL ENGINEER with managing editorial experience. This experience absolutely necessary. Application by letter. Location, New York State. V-1039.

ELECTRICAL SALES ENGINEER. Transformer specialist. Travel about half time. Application by letter. Headquarters, New York City. V-1041.

ELECTRICAL SALES ENGINEER. Electrical apparatus sales. Application in person by appointment. Location, New York City. V-1042.

ENGINEERS experienced in corrugated paper production. Application by letter. Salary not stated. Location, Brooklyn, N. Y. V-1068.

OPERATOR on corrugated paper machines. Application by letter. Location, Brooklyn, N. Y. V-1069.

FOREMAN OF BLACKSMITH and FORGE SHOPS. Will have under jurisdiction groups of men and must be man who understands requirements of occupations of following: Press and hammer Forgers, Blacksmiths, Furnace heaters and their various helpers. Must be tactful, resourceful, confident and be able to coordinate work of his department with that of other departments, such as machine shops, foundries, structural shop and locomotive repairs. Must be experienced blacksmith, familiar with general, light and heavy forgings such as connecting rods and main frames of large locomotives. To make forgings from drawings, templates or samples, such shapes as crank shafts, axles, heavy crane hooks and mill spindles. Must be experienced forge shop heater, familiar with large oil heating furnaces, 800-ton press and a 6000-lb. double stand forging hammer, heating and forging steel billets up to 30 inches. Must be capable of cutting, forging, shaping and hardening various kinds of high-speed steel or other grades of steel, all kinds and shapes of cutting tools required for the lathe, planer, boring mills and other machine tools, chisels, cutters and various special tools. Application by letter. Salary not stated. Location, Ohio. V-1076.

SALESMAN who is interested in heating appliances and has some electrical education. Company makes apparatus and salesman has chance to work up to production manager. Application by letter. Commission basis. Headquarters, New York City. V-1085.

ELECTRICAL ENGINEER. Should be college graduate of not less than 3 or 4 years experience and be familiar with design of d-c. motors as well as control apparatus. Experience in this line in connection with electric traveling cranes will be particularly valuable. Application by letter. Salary not stated. Location, Mich. V-1092.

EXPERIENCED SALES ENGINEER familiar with mechanical and electrical industrial plant equipment. We have 5 very high-class exclusive accounts in this territory, covering state of Conn., northern N. J. and N. Y. City, together with export trade. Not interested in man who has not had necessary sales experience or who has not ability and confidence in himself to be an asset to company on commission basis. Receive all inquiries in this territory from manufacturers whom we represent and at present time have more than we can handle. High-class man might secure 25 per cent interest in business and prefer man who would be interested financially. Application in person. Headquarters, New York City. V-1093.

ELECTRICAL ENGINEER with some experience in design of fractional horse power motors. Job is for a junior engineer but prospects for advancement to senior engineer are very encouraging. Our distinction between junior and senior engineers is that the former does routine work under the guidance of one of the latter who has responsible charge of design. Must be an American and must have graduated with degree of B. S. in electrical engineering from a University of good standing and must submit with application a photograph and three references in addition to a complete statement as to training and experience. Application by letter. Salary not stated. Location, Mo. V-1095.

SALESMAN, young man to sell radio apparatus. Have three propositions (1) salary, (2) commission, (3) exclusive arrangement. Application in person. Salary not stated. Headquarters, New York City. V-1096.

HIGH-CLASS SALES EXECUTIVE. Want a strictly honorable man as company has a secret process and interested rivals. Will have salesmen under his direction, must travel extensively. Must know spinning lathes, and have knowledge working of copper, aluminum and silver, as used in silverware, cooking pots, etc. High-class machinery salesman desired. Age 30-35. Headquarters, New York City. Application by letter. Salary and percentage of net sales. V-1134.

INSTRUCTOR. Electrical engineering. Must be technical graduate. Teaching or test experience desirable. Location, Ohio. V-1151.

MANAGER of small gas works and electric distribution. Must know gas manufacturing and have electric distribution experience. Application by letter. Salary not stated. Location, Pa. V-1158.

PUBLIC UTILITY SALES. Must have experience in central station work and also central station sales. Not less than 5 years experience. Graduate E. E. Application by letter. Salary not stated. Location, Pa. V-1159.

RECENT GRADUATES in mechanical or electrical engineering on relay adjustment work. Will be given training course. Age 20-28. Application in person. Location, New York City. V-1171.

YOUNG MEN. Age 20-28 years. Must have two years college or be a graduate in mechanical or electrical engineering. Will give three months training on circuit work. Application in person. Location, New York City. V-1172.

COLLEGE GRADUATES in mechanical or electrical engineering who have had some supervisory experience (about 4 or 5 years) on small interchangeable apparatus such as typewriters or adding machines or electric switchboards. Salary $30-40, per week. Application in person. Location, New York City. V-1173.

COLLEGE MEN with scientific education for estimating. Estimating to consist in costs of installation of electrical apparatus, cost of labor and material. Must have had estimating experience. Salary not stated. Application in person. Location, New York City. V-1174.

ASSISTANT SUPERINTENDENT of meter and test department. Must have executive ability, age 25-35 years, college education in electrical engineering, must have 5 years experience in central station work, have good knowledge of substation generator station switchboard wiring, switchboard instruments and relays, and must also have good knowledge of metering on consumer's premises, the methods of determining maximum demand and of alternating-current theory. Application by letter. Salary $2600-3000. Location, New York City. V-1182.

ELECTRICAL ENGINEER with extensive knowledge of station switchboard wiring and protective apparatus, and general laboratory testing. Age 25-35 years. Application by letter. Salary not stated. Location, N. Y. City. V-1183.

SALES ENGINEER for manufacturer of steel transmission poles and towers; must be well educated in electrical engineering, have working knowledge of steel construction; preferably man with experience in the sale of transmission towers. Give complete information as to education, experience, salary, trade experience, references. Also if possible, send photograph. Position has large possibilities for the right man. Headquarters Chicago, Ill. V-1191.

PRECISION METER (liquid) DEVELOPMENT ENGINEER. Must have had this experience. Application by letter. Salary not stated. Location, N. J. V-1217.

SALES ENGINEER must have experience in the design, manufacture and assembling of controllers. Only experienced man will be considered. Application by letter giving age, education and experience. Salary not stated. Location, Pa. V-1225.

ENGINEER to have charge of the assembling of controllers. Must have design and shop experience in this line of work. Only experienced man will be considered. Application by letter giving age, education and experience. Salary not stated. Location, Pa. V-1226.

SALES ENGINEERS for New York, Pittsburgh and Detroit. Every new man taken on will put in a period of from one to three months in the shop as an ordinary workman doing work that will be of value to him as a salesman, after which he will be put in the field on actual erection of product for a similar period, following this will be put in the Cleveland Office for a sufficient length of time to become familiar with forms and general policies. After this period will be put in one of our offices which are already established as a junior salesman, after which time salary will be determined by results. As we are contemplating opening new offices in Boston, Philadelphia, Buffalo, Chicago, Cincinnati, during the course of next two years, every man in sales department will have opportunity of qualifying for position of District Manager. Application by letter. Location, New York, Pittsburgh and Detroit. Headquarters, Cleveland. V-1229.

HEATING and VENTILATING ENGINEER. Will consider man who has 3-4 years heating and ventilating experience in contractors office. Men without this experience will not be considered. Application in person. Salary not stated. Location, New York City. V-1235.

SALES MANAGER of exceptional ability with electrical jobbing and retail experience. Knowledge of radio essential. Must be good executive and capable of organizing and keeping a large force of salesman working at top notch. Remuneration commensurate with ability; salary and bonus. Application by letter giving personal characteristics, business experience in detail and when services are available. Location New York City. V-1238.

MANAGER of engineering department to have charge of testing and installation of radio receivers, also of service department. Must be a good executive and an experienced radio engineer. Application by letter giving full details of experience, age, references and when services will be available. Salary not stated. Location, New York City. V-1239.

SUPERINTENDENT to look after a number of jobs of electrical construction work. Permanent position and should offer good opportunity for advancement, to the man who can fill it. Must have had much experience in practical electrical construction work upon buildings, power plants, etc., be able to handle men and must be ambitious and willing to work hard and assume responsibility. Application by letter. Salary not stated. Location, New Jersey. V-1252.

SALESMAN for radio apparatus. Application by letter. Commission and drawing account if desired. Headquarters, New York City. V-1253.

RADIO ENGINEER, thoroughly conversant with recent radio development, who is resourceful and thoroughly competent to work out problems incident to a radio set and necessary appurtenances thereto. Application by letter. Salary not stated. Location, New Jersey. V-1276.

ESTIMATOR, young, experience in estimating construction of overhead distribution and transformer installations in suburban districts. Position is with rapidly growing public utility in western New York. Pay moderate to start until applicant has demonstrated ability to earn more. Second choice young electrical student with good theoretical understanding of principles of overhead line construction and distribution. Exceptional opportunity for advancement. Application by letter giving all particulars. Location, New York State. V-1280.

YOUNG MAN to supervise the grinding of Manganese castings. Applicant must have had experience in this work. Location, Ohio. V-258.

ELECTRICAL ENGINEERS (2), age 26-32, for local managers or superintendents in charge of local offices, handling commercial work, maintenance and operation of low-tension lines for power and light distribution Protestant, American with operating and commercial experience preferably.

Trained for 1-4 months. Application by letter. Location, Pittsburgh, Pa. V-1286.

INSTRUCTOR IN ELECTRICAL ENGINEERING, Sept. 1st, in state institution of recognized standing. Will be given recitation and laboratory section in direct and alternating currents, largely dependent upon choice and preparation. Application by letter. Location Mid-West. V-1310.

INSTRUCTOR IN ELECTRICAL ENGINEERING beginning Sept., 1922. Application by letter. Salary not stated. Location, Pa. V-1312.

ENGINEER to take new development work from designing department and O. K. for production department. Radio experience essential. Application by letter giving age, education, experience. Must be at least 35 years of age. Location, New York City. V-1373. (Salary not stated).

TECHNICAL GRADUATE who has had a few years experience. Work will consist of drafting and field work in connection with hydraulic power house extensions, substation and transmission line designs and construction. Application by letter stating age, whether married or single, experience, education and amount of salary expected. Location, Pa. V-1382.

MEN AVAILABLE

ELECTRICAL ENGINEER—Technical graduate; Assoc. A. I. E. E., age 28. Six years experience in testing laboratory radio, chief engineer of marine installation and maintenance; remote control, machine tool application, estimating and construction work. Desires permanent position with well established company, planning, estimating and following up progress of jobs. Location preferred Newark or New York City; available one month. E-3349.

INSTRUCTOR—Electrical Engineer, age 28, technical graduate (degree B. S. 1917) licensed to teach in evening high schools, desires to teach, evenings, engineering subjects in institution within commuting distance of New York City. E-3350.

TRANSPORTATION ENGINEER—Age 26, B. S. in electrical engineering. Held a position as aid to consulting engineer making traffic and rate surveys for street railways. Capable of writing good engineering reports. At present employed on large system in the study of schedules and transportation. E-3351.

GRADUATE ELECTRICAL ENGINEER—Age 27, Single. Desires opportunity with railway company which operates some electrification. Practical experience in wiring and motor repairs. Has constructive ability. Available in ten days. E-3352.

YOUNG MAN—Age 23, single, will receive B. S. degree in electrical engineering next June. Student member A. I. E. E. Commercial course, speaks and writes Bohemian, studied Spanish. Location immaterial, foreign service considered. Not afraid of work. E-3353.

ELECTRICAL ENGINEER—Technical graduate, age 28; 1½ years on G. E. test, 2 years in electrical maintenance department of large brass factory, 1½ years on design and manufacture of small motors. Desires permanent position as electrical maintenance engineer of industrial plant or as assistant to consulting engineer. E-3354.

SALES ENGINEER, successful as branch office and sales manager as well as in personal selling, an experienced executive having manufacturing and engineering experience. Member A. I. E. E. and A. S. M. E. Location not material. Opportunity for advancement on merit, more important than large remuneration at start. Available at once. E-3355.

TECHNICAL GRADUATE, Age 26, B. S. in Engineering, with two years experience installing factory lighting and motors. Three months on Westinghouse Engineers course. Ten months with central station in charge of motor installation with remote control. Also maintenance and repair of electrical equipment. Has initiative ability. Desires position as assistant to executive E-3356.

MANUFACTURERS AGENT—California and Southwest. Sales engineer, age 37. Wide acquaintance with electrical and manufacturing industries. Successful sales experience. Member A. I. E. E. and A. E. C. S. Desires to represent reliable manufacturing concerns on commission basis, either as direct salesman, as agent or as distributor. Correspondence solicited. References furnished. E-3357.

MECHANICAL and POWER ENGINEER—Technical graduate, B. S. and M. E., eight years experience, machine shop, metallurgy, sugar engineering, industrial and power plant practise, operation, design, layout calculations, heat balance utilization and distribution of steam, water, coal, power, etc., investigation, research, reports. Executive and business ability. E-3358.

ENGINEERING SALESMAN—Age thirty. Ten years experience in design of fuse, and service boxes, meter testing devices and moulded insulations, also limited wireless experience. Recently completed local sales course. Desires connection with sales force of live electrical organization (Connecticut territory). Associate A. I. E. E. Available June 1st. E-3359.

ADMINISTRATOR-ENGINEER, expert knowledge Latin-American and Spanish Language, knowledge French, German, seeks general management tropical properties; or New York position as assistant to president, personnel director, secretary commercial association, executive with concern dealing with Latin-America, etc. E-3360.

ENGINEER of broad experience in electric steam and hydro-power plant work, in the capacities as superintendent, assistant or chief operator, covering all classes of power house, lines and substation construction. Age 41, married. Reference furnished upon request. E-3361.

GRADUATE ELECTRICAL ENGINEER, M. I. T. 1915, seven years broad experience in testing construction, maintenance and service work desires position as assistant superintendent or assistant to chief engineer of power company, or large industrial company. Would consider road position in service or application work. E-3362.

TECHNICAL GRADUATE (electrical), University of Wisconsin, age 33, single, desires position as engineer or assistant engineer with public utility company, but will consider any offer in any other capacity or in any other line. Nine years general engineering experience, most of which has been devoted to design, construction and operation of medium sized central stations, transmission lines and distribution systems. Now employed. Available after July first. E-3363.

ERECTOR—Four years experience, construction and installation. Executive ability. Technical training. American, age 26, married. Available July 1st. E-3364.

ELECTRICAL ENGINEER, B. S. in E. E., two years experience in transmission and distribution engineering for large Illinois Company; previously experienced in central station construction and operation, and in outside power wiring. Age 24 years. Desires responsible engineering position in or near Chicago. E-3365.

GRADUATE ELECTRICAL ENGINEER—University of Toronto, Canada, age 22, experienced in the supervision, construction, maintenance and operation of hydroelectric systems, with the Ontario Hydro-Electric Power Commission. Desires position with power company. Available on short notice. E-3366.

TECHNICAL GRADUATE. B. S. E. E. desires position in distribution, power sales or estimating department of central station company. Would be interested in utility bond and commercial sales work or work in patent attorneys office. Single age 26, present employed teaching. E-3367.

ENGINEER, technical graduate, 2 years G. E. Test, 2 years assistant chief in 50,000-kw. station, 1 year superintendent of betterment work in 3,000-kw. station and 55-ton ice plant, desires permanent connection with chance for advancement. Salary desired, $3,600. E-3368.

ELECTRICAL ENGINEERING STUDENT desires an opportunity with an engineering, manufacturing or contracting concern for the summer months with the expectation of making a permanent connection upon graduation in June 1923. Two years general business experience. Available end of June. E-3369.

TECHNICAL GRADUATE, MANAGER—Member A. I. E. E. and A. S. M. E. with fifteen years experience in railway and power distribution new business gas and electric, power house operation, transmission lines, large power, at present manager with company $250,000 year gross. Desires position as manager in city of 25,000 or superintendent light and power or superintendent new business in larger city. Successful executive, tactful and energetic in public relations. E-3370.

TECHNICAL GRADUATE, age 29, Assoc. A. I. E. E., 2 years G. E. test, 4 years responsible experience in steam power plants, now general superintendent 3000-kw. modern turbine station, small electric railway and 2 40-ton ice plants. Desires position with consulting engineer which offers chance for advancement. Present salary $3400. E-3371.

INSTRUCTOR—Technical graduate in electrical engineering who has had ten years practical experience with large manufacturer and public utilities desires to become instructor in some recognized college centrally located, where he can carry on consulting engineering work which would be to the best interest of the college and himself. E-3372.

GENERAL MANAGER—Over twenty years experience in construction, operation, management public utilities. General manager large railway, gas and power company prior to the war. Know the business from the coal pile to the public. Successful Executive, energetic and tactful. Age 47, married, American, several years experience abroad, speak Spanish, available now. E-3373.

PROFESSORSHIP OF MECHANICAL OR ELECTRICAL ENGINEERING desired. Must be an executive position. Teacher, engineer and writer. Age 33. E-3374.

HYDROELECTRIC OPERATING MAN, 15 years general power experience, past four years as superintendent of 40,000-h.p. hydroelectric station. Desires position with hydroelectric power company or pulp and paper interests. Will go anywhere. No objection to foreign service. E-3375.

YOUNG ENGINEER—Graduate, 4 years experience. Design and construction small hydroelectric stations. Substations of all kinds. Electrical circuits, switchboards. Desires position with engineers doing small hydroelectric developments or transmission lines. Would welcome experience in all phases of this class of work. E-3376.

ELECTRICAL ENGINEER—Experienced in operation, maintenance and design of power plants, at present employed as assistant superintendent of power company, desires a responsible position with progressive power company or large industrial plant. E-3377.

ENGINEER, Assoc. A. I. E. E., one year course practical engineering with Westinghouse Electric Company, East Pittsburgh, Pa. (six months test course) age 29, for sometime teacher of theoretical and practical electricity in Bahia-Brazil, speaks English and Portuguese fluently. Desires position in South America. E-3378.

ELECTRICAL ENGINEER desires teaching or industrial connection. Two years experience in night schools. Two years experience in incandescent lamp manufacture. No objection to travel but prefer East. Salary $2200. E-3379.

ELECTRICAL AND MECHANICAL ENGINEER—Graduate of the University of Michigan. Age 26. Qualified to undertake design of steam generating stations, studies of heat balance, etc. Experience in engineering department of large

public service corporation. Wishes position of responsibility in connection with construction of steam power plants. E-3380.

EXECUTIVE, COMMERCIAL ENGINEER—Graduate mechanical and electrical engineer, with factory and sales experience; extensive service in Europe and South America, covering construction, engineering, sales and exports; speaking French, with translation knowledge of Spanish and German. Also extensive experience in reports, appraisals, consolidations and claims. Desires position as executive or commercial manager, export or domestic, preferably sales or commercial engineering. E-3381.

ELECTRICAL ENGINEER, age 29, technical graduate, former engineering officer in U. S. Navy, desires connection with construction company, or public utility. Ten years experience with both line and inside construction, considerable experience installing and repairing motors, generators and switchboards. Good reference. Young man who is not afraid of work. E-3382.

EXECUTIVE AND SALES ENGINEER, with several years of actual experience in development and application of electrical apparatus to the industrial field, combined with mechanical engineering recommendations based on common sense methods. Desires position with manufacturing company, as representative or sales agent for electrical and mechanical apparatus or equipment, or with operating company as engineer of same. E-3383.

ELECTRICAL ENGINEER, Technical graduate, age 32, married; eight years experience in power plant, substation, underground distribution, lighting and industrial engineering. Capable of handling men and building an efficient organization. Available one month after agreement. Best of references furnished upon request. E-3384.

EXECUTIVE ENGINEER & MANAGER. Fel. A. I. E. E., M. A. Soc. C. E., nearly 20 years broad, general, active experience with large, high-voltage, hydroelectric systems, fully conversant to take charge of investigations, construction and management. Fully equipped to employ men and use materials under worst conditions met with in foreign countries and remote from manufacturers, and to maintain satisfactory operation. Can speak Spanish. At present in senior position of British Government service in Near East but leaving shortly. Married. Location anywhere. Salary $6000. E-3385.

GRADUATE ELECTRICAL ENGINEER—G. E. test, age 33, married. Have been chief safety engineer in workmen's compensation field; excellent experience in safety code work. Now doing technical and publicity work in general insurance; present salary $4500. Would accept responsibility for safety, insurance or analytical work in industrial plant or utility. E-3386.

GRADUATE ELECTRICAL ENGINEER—Age 32. Desires position with railway, Light or power company. Two years Westinghouse Elec. Co., testing dept. Two years experience on operation, maintenance and installation work of electrical equipment with industrial firm. Would appreciate opportunity to become connected with a public utility with opportunities for advancement. Would expect at least $1800 to start. V-3387.

ELECTRICAL ENGINEER. Married, age 29, nine years experience in installation, maintenance and operation of d-c. and a-c. motors, generators and turbines, inside and outside wiring, train lighting, electric locomotive maintenance and construction, power plant construction maintenance and operation. Associate A. I. E. E. Speaks French and German. Have taken Civil Service examination and attained grade 80 per cent. Reference. Will go anywhere where there is chance for promotion. E-3388.

ELECTRICAL ENGINEER—graduate, considerable general laboratory practise and industrial engineering experience desires position offering good future. Theoretical and practical on radio. Age 27. Salary dependent upon position and location. E-3389.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MAY 19, 1922

AMES, ALFRED C., Chief Electrician, Providence Gas Company, Sassafras Point, Providence, R. I.

ANDERSON, GEORGE NATHANIEL, Transmission Engineer, N. W. Bell Telephone Company; res., 4024 Chicago Ave., Minneapolis, Minn.

BAARSRUD, KNUD, Consulting Engineer, Mogens Thorsens gade 9, Kristiania, Norway.

BACON, HAROLD RALPH, Sales Agent, General Electric Company, New Haven; res., 28 Academy Hill, Derby, Conn.

BAILEY, WILLIAM HENRY, Technical Assistant, Bureau of Engineering, Navy Dept; res., 2405 12th St., N. E., Washington, D. C.

BARNETT, WALTER, Chief Clerk, Construction Division, Distribution & Installation Dept., New York Edison Co., 130 E. 15th St., New York; res., 48 Woodside Ave., Woodside, N. Y.

*BAZZEGHIN, FORTUNATO, Electrical Draftsman, Thomas E. Murray Company, Inc., 55 Duane St., New York, N. Y.; Hamden, Conn.

BEACH, ALBERT BENJAMIN, District Sales Manager, Ludwig Hommel Company, 917 Rose Bldg., Cleveland, Ohio.

BELANGER, ERNEST, Shift Operator, Laurentide Power Company, Grand Mere, P. Q., Canada.

BELL, BENNIE HAYSE, Chief Electrician, New Orleans Railway & Light Company, New Orleans, La.

BENARD, ARTHUR G., Assistant Sales Manager, Locke Insulator Corp., Victor, N. Y.

BHOLE, SHANKER JAIRAM, 261 Broadway; res., 221 West 23rd St., New York, N. Y.

BISSET, GEORGE, Relay Inspector, Potomac Electric Power Company; res., 3601 Hall Place, Washington, D. C.

BLAKE, G. WALDRON, Standardizing Laboratory, General Electric Company; res., Y. M. C. A., Lynn, Mass.

BLINCOE, LEMUEL REED, Testing Dept., General Electric Company; res., 779 State Street, Schenectady, N. Y.

BOWER, GERALD A., Ice Machine Production, General Electric Company; res., 1212½ Broadway, Ft. Wayne, Ind.

BOWNE, LANGFORD J., Telephone Engineer, Western Electric Company, 463 West St., New York; res., Howard Beach, N. Y.

BRAUN, CARL EDWIN, Assistant Chief Electrician, Crown Willamette Pulp & Paper Company, Camas, Wash.

BRECKEL, HARRY FREDERICK, Vice-President, General Manager, The Precision Equipment Company, Inc., 2437 Gilbert Ave., Cincinnati, Ohio.

BROKEMYR, JOSEPH EVALD, Utah Power & Light Company, Terminal Substation, 133 South West Temple St., Salt Lake City, Utah.

BROWN, ROY ATKINSON, Assistant Professor, Electrical Engineering, Ohio State University, Columbus, Ohio.

BUCKLEY, WILLIS A., Superintendent, Substations, The Indiana & Michigan Electric Company, 102 N. Michigan St., South Bend, Ind.

BURMEISTER, HARRY WILLIAM, Substation Operator, Commonwealth Edison Company, 72 W. Adams St.; res., 708 Diversey Parkway, Chicago, Ill.

CAMPBELL, TRISTRAM JOSEPH, Technical Report Writer, General Electric Company; res., 17 Sagamore St., Lynn, Mass.

*CARDENAS F., ARMANDO, Engineer, Monterey Iron & Steel Works, Apartado 206, Monterey, N. L., Mexico.

CAROTHERS, FRED N., General Foreman, Substations, Boston Electric Railway Company, 439 Albany St., Boston, Mass.

CHARBONNEAU, L. HENRY, Electrical Draftsman, Southern California Edison Company, Edison Bldg., Los Angeles; Orange, Calif.

CHESTNUT, D. LEE, Small Motor Sales Dept., General Electric Company; res., 172 Washington St., Lynn, Mass.

CHIPPERFIELD, JOHN WILLIAM, Ferranti Meter & Transformer Mfg. Co., Ltd., 26 Noble St.; res., 127 Spruce Hill Road, Toronto, Ont., Canada.

CLEMENTS, ALBERT H., Sub-Foreman, General Electric Company, Lynn; res., 15 Bayview Ave., Nahant, Mass.

CRIDER, NED, Engineering Dept., Union Electric Light & Power Company, Lockwood & McClure Sts., Webster Groves, Mo.

CULVER, CHARLES O., General Superintendent, Eastern Shore Gas & Electric Company, Salisbury, Md.

DAVIS, DEAN W., Charge of Engineering Dept., Dudlo Mfg. Company, Wall St.; res., 1425 Columbia Ave., Ft. Wayne, Ind.

DAVIS, ROBERT VERNON, Southern Bell Tel. & Tel. Company, Montgomery, Ala.

DAWSON, JOSEPH CHESTER, Standardizing Laboratory, General Electric Company; res., 11 Baker St., Lynn, Mass.

DILKS, ARTHUR GWYNNE, Service Engineer, Canadian General Electric Company, 212 King St. West, Toronto, Ont., Canada.

DRAYTON, WALTER, Electric Service Inspector, Bureau of Power & Light, City of Los Angeles; res., 702 N. Olive Ave., Alhambra, Calif.

EISENSTADT, MAURICE, Designing Engineer, Henry R. Kent & Company, 5 Erie Ave., Rutherford, N. J.; res., 1051 Union Ave., New York, N. Y.

ELLIOTT, MARION BELLFIELD, Testing Dept., General Electric Company; res., 779 State St., Schenectady, N. Y.

ELLIS, RALPH DELORIEA, Engineer, Thomson Laboratory, General Electric Company; res., 57 Tucker St., Lynn, Mass.

*EPSTEIN, HIRSCH, Chief Engineer, Hyperbo-Electric Flow Meter Company; res., 2523 Lexington St., Chicago, Ill.

ERICKSON, FRANK WILLIAM, Foreman, The New York Edison Company, 715 1st Ave., New York, N. Y.; res., 207 15th St., West New York, N. J.

ERVINE, WILLIAM G., Operator, Baltimore Consolidated Gas & Electric Company, Westport Power House, Baltimore; res., 1303 Belair Road, Raspeburg, Md.

FETZER, CARL McATEE, Circuit Designer, Western Electric Company, 463 West St., New York, N.Y.; res., 180 E. Pierrepont Ave., Rutherford, N. J.

FISKE, JOHN M., Instructor, Electrical Engineering, Montana State College, Bozeman, Mont.

FOLSOM, SHERMAN I., Superintendent of Substations, Potomac Electric Power Company, 231 14th St., N. W., Washington, D. C.

FRASER, VERNESS, Denver Gas & Electric Light Company, Denver, Colo.

FROST, LLOYD WILKIN, Assistant Electrical Engineer, Erner & Hopkins Company; res., 224 Crestview Road, Columbus, Ohio.

GATES, ARTHUR HENRY, Assistant Foreman, Thomson Laboratory, General Electric Company, Lynn; res., 16 Beach St., Revere, Mass.

GAUSS, CHARLES HENRY, Electrical Mechanic, Penna. Water & Power Company; res., 2402 E. Fayette St., Baltimore, Md.

GOMER, LOUIS F., Chief Electrician, British American Mfg. Company, Victory Mills, N. Y.

GRABLE, JOSEPH PATRICK, Engineering Dept., Dudlo Mfg. Company; res., 518 W. Wayne, Ft. Wayne, Ind.

GRAFF, MURRAY GENSEL, Supply Salesman, Westinghouse Elec. & Mfg. Co., 1062 Gas & Electric Bldg., Denver, Colo.

GRECE, CHARLES JOSEPH, Assistant General Foreman, The New York Edison Company, 715 1st Ave., New York, N. Y.

GREER, HUGH DUNLAP, Low Tension Dispatcher, Potomac Electric Power Company, 510 10th St., N. W.; 1445 Massachusetts Ave., N. W., Washington, D. C.

GUTIERREZ, MIGUEL MESA, Testing Dept., General Electric Company, Schenectady, N. Y.

HAHN, HAROLD W., District Sales Manager, Duplex Lighting Works, General Electric Company, 6 W. 48th St., New York; res., 640 DeKalb Ave., Brooklyn, N. Y.

HALL, MERTON COLVIN, Dept. of Development & Research, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.; res., 115 Delevan Ave., Newark, N. J.

HALLE, SIMON, Sales Engineer, Edison Electric Appliance Company, Inc., Commercial National Bank Bldg., Washington, D. C.

HANCOCK, WINFIELD SCOTT, Instructor of Electricity, University of California, Los Angeles; res., 227 N. Templeton St., Huntington Park, Calif.

HARDAWAY, WARREN DUNHAM, Assistant Electrical Engineer, Denver Gas & Electric Light Company, Denver, Colo.

HARRINGTON, JOHN W. Treasurer, Harrington & Richardson Arms Company, 320 Park Ave.; res., 1014 Main St., Worcester, Mass.

HARTMANN, ZOLTAN, President & General Manager, Zoltan Hartmann Electric Co., 261 E. 78th St., New York, N. Y.

HATTON, WESLEY LEONARD, Switchboard Operator, Station F. Potomac Electric Power Company; res., 710 Rock Creek Church Road, N. W., Washington, D. C.

HAUSS, ALBERT F., Manager, Albert F. Hauss Company, 4 W. 3rd St., Cincinnati, Ohio.

HAYAT, SHAIK MOHMED, State Electrical & Mechanical Engineer, Udaipur, Meywar, Rajputana, India.

HENDERSON, WILLIAM McCREARY, Bedaux Engineering, General Electric Company; res., 15 Tudor St., Lynn, Mass.

HERMANCE, CARL HERMAN, Substation Operator, Municipal Gas Co.; res., 312 Haven Ave., New York, N. Y.

HIXSON, ARTHUR GLENN, Foreman, Electrical Construction, West Penn Power Company, Springdale, Pa.

HOLDEN, WILLIAM HENRY TOWNE, Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

HOLLEY, OTTO B., Electrical Engineer, Michigan Northern Power Company; res., 207 Barbeau St., Sault Ste. Marie, Mich.

*HOPPER, FRANCIS LOGAN, Senior, California Institute of Technology; res., 315 S. Mentor St., Pasadena, Calif.

HORN, GEORGE B., Sales Engineer, Dudlo Mfg. Company, Wall St., Ft. Wayne, Ind.

*HOWIE, JOHN LLOYD, JR., Senior, Electrical Engineering, University of Illinois; res., 702 W. Main St., Urbana, Ill.

HULL, JOHN PATRICK, Office Manager, Chatham Electric Engineering, Inc., 1966 Broadway; res., 211 W. 115th St., New York, N. Y.

HUNTZICKER, PAUL, Municipal Engineer, 717 Thatcher Bldg., Pueblo, Colo.

HUTTON, WILLIAM THOMAS, Engineer, Interstate Light & Power Company, Galena, Ill.

INOUYE, IKUTARO, Electrical Engineer, Japanese Government Railways, Tokio, Japan; Mitsui & Company, No. 31-33 Lime St., London, E. C. 3, Eng.

ITO, MASAJI, Electrical Engineer, Kawasaki Zosensho, Kobe, Japan.

JACKSON, DONALD J., Sales Dept., Dudlo Mfg. Company; res., 801 W. Wildwood Ave., Ft. Wayne, Ind.

JAMESON, GEORGE S., Supervisor, Order & Stock Dept., General Electric Company, W. Lynn; res., 26 Farragut Road, Swampscott, Mass.

JENKINSON, JOHN, Supt., Meter Dept., British Columbia Electric Railway Company; res., 992 Howe St., Vancouver, B. C.

JOHNSON, GUS ALVIN, Telephone Engineer, Pacific Telephone & Telegraph Company, Portland, Ore.

JOHNSON, HERBERT BRIGHTWELL, Engineer, Western Electric Company, 463 West St., New York; res., 85 Halsey St., Brooklyn, N. Y.

JOHNSON, VERNE E., Superintendent, Steam Plant, The Southern Sierras Power Company, 1615 Poplar St., San Bernardino, Calif.

JONES, RUFUS G., Superintendent, Meter Dept., The Southern Sierras Power Company, Riverside, Calif.

*JONES, WALTER LELAND, JR., Local Manager, Union Electric Light & Power Company, St. Charles, Mo.

KAUPP, CHARLES OTTO, Instructor, Electrical Construction, Williamsport High School; res., 700 Campbell St., Williamsport, Pa.

KEENEY, JOHN WESLEY, Chief Engineer, Power Station, Virginia Railway & Power Company, Norfolk; res., 14 Middle St., Portsmouth, Va.

KELLER, EDWARD LEONARD, Tester of Electrical Apparatus, Duquesne Light Company; res., 259 Oakland Ave., Pittsburgh, Pa.

KELLEY, CHARLES F., Electrical Engineer, Patrick McGovern, Inc., 50 E. 42nd St., New York; res., 1594 Hayes Ave., Elmhurst, N. Y.

KELLY, NICHOLAS J., Engineer & Chief Estimator, Chatham Electric Engineering, Inc., 1966 Broadway, New York, N. Y.

KERSHAW, WALTER F., Foreman, General Electric Company; res., 41 Market St., Lynn, Mass.

KING, CARL M., Electrical Designer, Fairbanks, Morse & Company; res., 1220 S. 36th St., Indianapolis, Ind.

KIRK, J. NEWTON, Outside Plant Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

KIRK, WALTER B., Superintendent, Overhead Lines, Lynn Gas & Electric Company, Lynn; res., 81 Lakeview Ave., E. Lynn, Mass.

KOIKE, SHIGEO, Electrical Engineer, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

KUSOMOTO, SOJIRO, In charge, Transformer Dept., Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

LACKIE, WALTER J., Designing Draftsman, French & Hubbard, 210 South St., Boston, Mass.

LAPP, G. W., Chief Engineer, Lapp Insulator Company, Inc., LeRoy, N. Y.

LEWIS, R. ARNOLD, District Flow Meter Specialist, General Electric Company, Cincinnati, Ohio.

LIPSON, EDWARD, Electrical Experimental Tester, General Electric Company, West Lynn, Mass.

LORD, MARK G., Superintendent, Power Plant & Shops, Arkansas Valley Railway, Light & Power Company, Pueblo, Colo.

LUCEK, CHARLES WILLIAMS, Telephone Engineer, Western Electric Company, 463 West St.; res., 1454 First Ave., New York, N. Y.

MANBY, AARON WOODROOFFE, Assistant to Superintendent, Queenston Power House, Hydro-Electric Power Commission of Ontario, Niagara Falls South, Ontario.

MATTHIEU, J. CLARENCE, Power Engineer, Dayton Power & Light Company, Dayton, Ohio.

McBRIDE, HENRY JOSEPH, Commercial Inspector, General Electric Company; res., 69 Mall St., Lynn, Mass.

McCAMMON, FLOYD FRANKLIN, Power Sales Engineer, Denver Gas & Electric Light Company, Denver, Colo.

McDERMOTT, JOHN ALVIN, Electrical Engineer & Master Mechanic, Chapman Price Steel Company, Indianapolis, Ind.

McDONALD, VARNON MICHAEL, Superintendent of Transmission, Colorado Power Company, 828 Symes Bldg., Denver, Colo.

McKNIGHT, ROBERT, Chief Electrician, Britannia Mining & Smelting Company, Ltd., Britannia Beach, B. C.

MILBURN, WILLIAM I., Electrician, Phoenix Utility Company, Allentown, Pa.

MOHR, CARL HERMANN, Commercial Engineer, E. I. Rosenfeld & Company, Inc.; res., 2135 W. Baltimore St., Baltimore Md.

MOORE, ERNEST ELLSWORTH, Engineer, Electric Bond & Share Company, 71 Broadway, New York, N. Y.

MULVANY, FREDERICK ARTHUR, Sales Engineer, Pacific States Electric Company, 570 1st Ave. South, Seattle, Washington.

MYERS, CARL M., Superintendent, Bare Wire Mills, Dudlo Mfg. Company; res., 1422 Eagle St., Ft. Wayne, Ind.

NATARAJAN R., Inspector, Instrument Section, Electrical Dept., The Bombay Telephone Co., Ltd.; res., 87 3rd Floor, Marker's Bldg., Khetwadi Main Road No. 4, Bombay, India.

*NEAL, D. E., District Sales Agent, Century Electric Company, St. Louis, Mo.; 171 2nd St., San Francisco, Calif.

NEUMAN, ROBERT, Local Superintendent, The Southern Sierras Power Company, Corona, Calif.

*NICHOLSON, CHARLES JAMES, 258 West 94th St., New York, N. Y.

NISHI, EISUKE, Electrical Engineer, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

O'BOYLE, GARDNER JAMES, Instructor, Mathematics & Electricity, Rehabilitation School, Catholic University, Brookland, D. C.

O'CONNOR, CHARLES EDWARD, Foreman, Construction Div., Distribution Dept., New York Edison Co., 15th St. & Irving Place; res., 745 Forest Ave., New York, N. Y.

OHNISHI, SADAHIKO, Transformer Designer, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

OKUWA, SATORU, Rheostat Designer, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

OLDFIELD, ROBERT TOPHAM, Electric Operator, Potomac Electric Power Company, Substation No. 3; res., The Dresden Apts., Connecticut Ave. & Kalaroma Road, N. W., Washington, D. C.

PEERS, GEORGE THOMAS, Operator, Potomac Electric Power Company, Washington; res., 224 Maple Ave., Takoma Park, D. C.

*PFLEIDERER, CHARLES ARTHUR, JR., Student, Electrical Engineering, Purdue University, Lafayette, Ind.; 2118 Napoleon Blvd., Louisville, Ky.

POSTON, VIRGIL, Superintendent of Operation, New York & Queens Electric Light & Power Company, Electric Bldg., Bridge Plaza, Long Island City, N. Y.

PRINGLE, JOHN ALBERT, Manager, Radio Dept., New Jersey Electric Company, 207 Washington St.; Newark; res., 227 Cleveland Ave., Harrison, N. J.

PUTNAM, ARTHUR CLAIR, Engineer, The Southern Sierras Power Company, Riverside, Calif.

QUANDT, WILLIAM, Foreman, Meter, Installation & Service Dept., Arkansas Valley Light & Power Company, Pueblo, Colo.

RANKIN, DAVID CECIL, Consulting Engineer, 723 W. 66th St., Chicago, Ill.

REGAN, JOSEPH PHILIP, Electrical Engineer, Trump Mfg. Company, Springfield, Ohio; res., 3 Wabash Ave., Worcester, Mass.

RICHARDSON, HARVEY RUSSELL, Assistant Engineer, Standardizing Laboratory, General Electric Company, W. Lynn, Mass.

RINGSDORF, CHARLES ALBERT, Electrician, The Rawplug Company, 461 8th Ave.; res., 1234 Prospect Ave., New York, N. Y.

RYAN, JAMES JOSEPH, Foreman, Construction Dept., Brooklyn Edison Company, 569 Fulton St.; res., 658 Park Place, Brooklyn, N. Y.

SANGREE, ERNEST MANN, Plant Engineer, New York Telephone Company, 227 E. 30th St., New York, N. Y.

SCHAD, JAMES HALL, Electrician, Phoenix Utility Company, New York, N. Y.; 114 S. 6th St., Allentown, Pa.

*SCHEER, GEORGE BURBRIDGE, Electrical Engineer, Westinghouse Elec. & Mfg. Company, E. Pittsburgh; res., 920 Franklin Ave., Wilkinsburg, Pa.

SCHEPPERLY, JOSEPH A., Electrical Engineer, American Gas & Foundry Co.; res., 5321 Pennsylvania Ave., Detroit, Mich.

SCHROEDER, CARL J., General Cable Foreman, Cleveland Electric Illuminating Company, Cleveland; res., 3000 Center Road, Warrensville, Ohio.

SEABURG, ALGODT JULIUS, Electrical Designer, with Charles T. Main, 201 Devonshire St., Boston; res., Magnolia, Mass.

SEIBERT, H. W., Construction Dept., General Electric Company, 701 Electric Bldg., Portland, Ore.

SEMMENS, CLIVE THOMAS KITCHENER, Electrical Tester, British Thomson-Houston Company, Rugby, Eng.

SENAUKE, ALEXANDER, Assistant in Electrical Engineering, New York University; res., 145 West 129th St., New York, N. Y.

SHARP, FRED R., Foreman, General Electric Co., Lynn; res., 1 Willis St., E. Saugus, Mass.

SHEPHERD, ROSWELL LINSLEY, Assistant Editor, McGraw-Hill Company, 10th Ave. 36th St., New York, N. Y.; res., 735 Lake St., Newark, N. J.

SHOBER, WILBUR MADISON, Switchboard Wireman, Cleveland Electric Illuminating Company; res., 11611 Saywell Ave., Cleveland, Ohio.

*SKINKER, MURRAY FONTAINE, Student, Oxford University, Exeter College, Oxford, England.

SMIRNOFF, ALEXANDER I., Engineering Dept., Potomac Electric Power Company; res., 1644 Argonne Terrace, N. W., Washington, D. C.

SMITH, ALLAN J., Inspecting Engineer, Columbus Railway, Power & Light Company; res., 284 E. 8th Ave., Columbus, Ohio.

SMYSER, FREDERIC HAWLEY, General Electric Company, West Lynn, Mass.

SOUZA, MANUEL ENOS, Electrical Engineer, General Electric Company, Caixa Postal 547, Sao Paulo, Brazil, S. A.

SPARROW, MAXWELL E., Patent Lawyer, 15 Park Row, New York, N. Y.

SPEAKMAN, EDWIN GRANT, JR., System Operator, Bennings Plant, Potomac Electric Power Company; res., 720 6th St., S. W., Washington, D. C.

SPRENGER, GEORGE WALTER, Draftsman, General Electric Company; res., 14 Sherman Terrace, Lynn, Mass.

STARR, JAMES HAMMOND, Sales Engineer, Carroll Electric Company, 714 12th St., N. W., Washington, D. C.

*ST. CLAIR, HARRY PRENTICE, Testing Dept., General Electric Company; res., 29 Norwood Ave., Schenectady, N. Y.

STEVENSON, CLYDE DUNCAN, Holter Plant, Montana Power Company, Wolf Creek, Mont.

STONE, GEORGE SHELAR, General Superintendent, The New Jersey Power & Light Company, 30 W. Blackwell St., Dover, N. J.

STONE, WILLIAM CLAYTON, Foreman Load Dispatcher, Marion Power Station, Public Service Electric Company; res., 104 Romaine Ave., Jersey City, N. J.

SWEENEY, DENIS, Assistant Foreman, General Electric Company, W. Lynn; res., 787 Summer St., Lynn, Mass.

SWEENEY, EUGENE C., Turbine Dept., General Electric Company; res., 787 Summer St., Lynn, Mass.

TAKAGI, MOICHI, Chief Engineer, Kobe-Himeji Electric Railway Company, Kobe, Japan.

TARMON, RAY F., General Foreman, Magnet Wire Dept., Dudlo Mfg. Company; res., 353 Randolph St., Ft. Wayne, Ind.

TEMPLE, JOHN C., Chief Electrician, Columbus Railway, Power & Light Company, 104 N. 3rd St., Columbus, Ohio.

TERRY, FRANCIS MARSHALL, Testing Dept., New York Edison Company, 92 Vandam St., New York; res., 110 S. Portland Ave., Brooklyn, N. Y.

THISTLETHWAITE, GORDON JOSEPH, Assistant Electrical Superintendent, Abitibi Power & Paper Company, Ltd., Iroquois Falls, Ontario.

THOMPSON, BENJAMIN HARRISON, Electrical Engineer, General Electric Company; res., 614 Terrace Place, Schenectady, N. Y.

THOMPSON, EARL A., Central Office Repairman, The Pacific Tel. & Tel. Company; res., 137 N. 81st St., Seattle, Wash.

THOMSON, DAVID P., Engineering Dept., General Electric Company, W. Lynn, Mass.

TOKAI, SHINZO, Electrical Engineer, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

VAN LOAN, CULLEN G., Electrician, Cooper Amusement Company; res., 316 S. 4th St., LaCross, Wis.

VAN WAGNER, PAUL, Superintendent of Distribution, Richmond Light & Railroad Company, New Brighton; res., 825 Delafield Ave., West New Brighton, N. Y.

VOYACK, FRANK, Foreman, Construction Dept., The Moto-Meter Co., Inc., 15 Wilbur Ave.; res., 73 18th Ave., Long Island City, N. Y.

*WAECHTER, FREDERICK AARON, Electrician's Mate, 3rd Class, *U. S. S. Pennsylvania*, San Francisco, Calif.; res., 55 Park Ave., Passaic, N. J.

WATTS, MYERS G., Supervisor, Philadelphia, Electric Company; res., 602 E. Hilton St., Philadelphia, Pa.

WHITE, CHARLES, Telephone Engineer, Western Electric Company, 463 West St., New York, N. Y.; res., 525 N. Grove St., E. Orange, N. J.

WICKERT, LELAND ALBERT, Installer & Repairman, W. L. Evans; res., 715 E. Fulton St., Lancaster, Pa.

WILLIAMS, MARION STARR, Engineering Dept., Western Electric Company, 463 West St., New York; res., 60 South 23rd St., Flushing, N. Y.

*WILSON, GUY EVERETT, Assistant Chief Draftsman, J. Edward Ogden Company, Inc., 147 Cedar St., New York, N. Y.

WOOD, JOHN WILLIAM, Chief Draftsman, City of Seattle, Skagit River Power, 1400 Alaska Bldg., Seattle Wash.

YOKOI, NOBUYOSHI, Designer, Electric Locomotive, Hitachi Engineering Works, Sukegawa, Ibarakiken, Japan.

Total 184.

*Formerly Enrolled Students.

ASSOCIATES REELECTED MAY 19, 1922

GARRETT, ANTHONY M., Field Engineer, Commonwealth Edison Company, 72 W. Adams St., Chicago, Ill.

JOSLIN, ARBA VANDERBURG, Assistant Engineer, Pacific Gas & Electric Company, San Francisco, Calif.; res., 1007 Kenmore Blvd., Kenmore, Ohio.

SATTERTHWAITE, J. PAUL, Plant Dept., American Tel. & Tel. Company, 195 Broadway, New York, N. Y.; res., 874 Westfield Ave., Elizabeth, N. J.

MEMBERS ELECTED MAY 19, 1922

DE LAY, ROY E., Kellogg Switchboard & Supply Company, 62 Kiangse Road, Shanghai, China.

FROST, FRANK G., General Superintendent, Electrical Dept., New Orleans Railway & Light Company, 201 Baronne St., New Orleans, La.

HORTON, REUBEN HARLAND, Traffic Engineer, Philadelphia Rapid Transit Company, 1520 Spruce St.; res., The Stonehurst, 454 Osage Ave., Philadelphia, Pa.

LASH, NORWOOD MAXWELL, Chief Engineer, Bell Telephone Company of Canada, Montreal, Que.

McRAE, GEORGE WADSWORTH, Toll Traffic Engineer, American Tel. & Tel. Company, 212 W. Washington St., Chicago, Ill.

O'BRYAN, FRANCIS LAFAYETTE, District Manager, Edison Electric Illuminating Company, 44 Union Ave., Framingham, Mass.

PORTENGEN, J. A., Soengeiliat, Banka, Dutch East Indies.

PULLEN, FRANK, President, Swedish General Electric Ltd., 107 Duke St., Toronto, Ont., Canada.

SCHUMACHER, R. J., Electrical Engineer, Kelley Island Lime & Transport Company, Marblehead, Ohio.

SHEPHERD, DAVID G., General Manager, Electric Specialty Company, 211 South Street, Stamford, Conn.

SMITH, JOHN HAYS, Engineer, Electric Light & Power, Public Service Commission of Pa., Harrisburg, Pa.

SMITH, PHILIP SEABURY, Associate Editor, McGraw-Hill Company, Inc., 10th Ave. & 36th St., New York, N. Y.

SMITH, WILLIAM LINCOLN, Professor of Electrical Engineering & Head of Dept., School of Engineering, Northeastern University, 316 Huntington Ave., Boston, 17, Mass.

WELLS, LOREN STANFORD, Electrical Superintendent & Superintendent of Telegraph, Long Island Railroad Company, Pennsylvania Station, New York, N. Y.

WOOLSEY, CLARENCE V., Assistant to Electrical Engineer, Brooklyn Edison Company, 360 Pearl St., Brooklyn, N. Y.

FELLOW ELECTED MAY 19, 1922

deARTIGAS, JOSE ANTONIO, Managing Director, Artigas & Company, Arrieta, 4, Madrid, Spain.

TRANSFERRED TO GRADE OF FELLOW MAY 19, 1922

CARPENTER, HENRY C., Chief Engineer, New York Telephone Co., New York, N. Y.

CHESTERMAN, FRANCIS J., Chief Engineer, Bell Telephone Co. of Pennsylvania, Philadelphia, Pa.

KITTREDGE, CARLYLE, Chief Engineer, Michigan State Telephone Co., Detroit, Mich.

WATERSON, KARL W., Assistant Chief Engineer, American Tel. & Tel. Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER MAY 19, 1922

BALL, WILLIAM J., President, Tri-City Electric Co., Moline, Ill.

BLATHERWICK, A. B., Electrical Planner, Navy Yard, Puget Sound, Bremerton, Wash.

BOYER, LEE, General Manager, Consolidated Power & Light Co., Deadwood, S. D.

CARPENTER, FRANK B., Electrical Engineer, West Virginia Engineering Co., Charleston, W. Va.

EGNER, ROBERT J., Section Engineer, American Tel. & Tel. Co., New York, N. Y.

GREEN, IRVING W., Engineer, Dept. of Development & Research, American Tel. & Tel. Co., New York, N. Y.

KING, ROBERT P., Works Engineer, East Springfield Works, Westinghouse Elec. & Mfg. Co., Springfield, Mass.

LATZER, FREDERICK, Electrical Engineer, Van Wagoner Linn Construction Co., New York, N. Y.

MEYER, HANS J., President, Charles L. Pillsbury Co., Minneapolis, Minn.

SCHNABEL, JAMES F., Assistant Sales Engineer, Electric Controller & Mfg. Co., Cleveland, O.

SMITH, HAROLD R., Partner in Smith, Robinson & Co., Vancouver, B. C.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held May 16, 1922, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

ALLEN, EDWIN W., Asst. District Manager & District Engineer, General Electric Co., Chicago, Ill.

ALLEN, ELBERT G., Chief Engineer, Philadelphia Rapid Transit Co., Philadelphia, Pa.

JAMIESON, BERTRAND G., Engineer of Inside Plant, Commonwealth Edison Co., Chicago, Ill.

PENNELL, WALTER O., Chief Engineer, Southwestern Bell Telephone Co., St. Louis, Mo.

SMITH, ARTHUR BESSEY, Chief Research Engineer, Automatic Electric Co., Chicago, Ill.

TAYLOR, EDWARD, Electrical Engineer, General Electric Co., Chicago, Ill.

To Grade of Member

ARMBRUST, GEORGE M., Engineer, Electrical Engineer's Office, Commonwealth Edison Co., Chicago, Ill.

BÂDGER, CHARLES K., Chief Engineer, Empressa Electrica de Guatemala, Gerente Empresa del Alumbrado Electrico del Norte, Guatemala City, Guatemala, C. A.

BOSE, SURENDRA NATH, Engineer, Electrical Dept., Perin & Marshall, New York, N. Y.

DEBEECH, ALBERT V., Electrical Research Engineer, Interborough Rapid Transit Co., New York, N. Y.

DES CAMPS, EDWIN J., Sales Engineer, Western Electric Co., Inc., Seattle, Wash.

GILBERT, HENRY C., JR., Construction Superintendent, W.A. Jackson Co., Chicago, Ill.

JOYCE, HARRY B., Chief Engineer, Centrifugal Fan Co., Newark, N. J.

KOBAK, EDGAR, Manager, *Electrical World, Electrical Review*, and *Industrial Engineer*, New York, N. Y.

KOUWENHOVEN, WILLIAM B., Associate Professor of Electrical Engineering, Johns Hopkins University, Baltimore, Md.

LA MOTTE, WILLIAM R., Chief Engineer, Perth Amboy Power Station, Public Service Electric Co., Perth Amboy, N. J.

OSGOOD, HARRY W., Electrical Engineer, McClellan & Junkersfeld, Inc., New York, N. Y.

ROBINSON, CHARLES G., Superintendent, Electric Power Plants, Union Electric Light & Power Co., St. Louis, Mo.

ROCKWELL, ROBERT L., Consulting Engineer, Seattle, Wash.

STEVENS, ROGER B., Electrical Engineer, Consulting Board, American Sugar Refining Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute, the list indicating the geographical district and Section in which the applicant is at present located. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1922.

Geographical District No. 1.

Boston Section

Connell, Lawrence H., Boston, Mass.
Goldsmith, Adolph, Boston, Mass.
White, Charles H. M., Cambridge, Mass.

Connecticut Section

Bird, Jewett D., Waterbury, Conn.
Bradshaw, Thomas N., New Haven, Conn.
Morris, Shiras (Member), Hartford, Conn.
Nash, Henry L., W. Haven, Conn.
Poole, James, New Haven, Conn.

Lynn Section

Adams, Harold, Lynn, Mass.
Campbell, Charles E., (Member), Lynn, Mass.
Darling, Nelson J., (Member), W. Lynn, Mass.
Halvorson, Cromwell A. B., Jr., (Member), Lynn, Mass.
Hamill, Daniel E., Lynn, Mass.
Norman, Horace E., (Member), Lynn, Mass.
Ross, Frank C., Lynn, Mass.
Sampson, Archibald T., Lynn, Mass.

Schenectady Section

Foust, Clifford M., Schenectady, N. Y.
Menon, V. K. Aravindaksha, Schenectady, N. Y.
Potter, Melville R., Syracuse, N. Y.
Total 19.

Geographical District No. 2

Akron Section

Flanigan, John M., Alliance, Ohio
Haushalter, Fred L., Akron, Ohio

Cincinnati Section

Kuhlman, Lee G., Covington, Ky.
Landis, George H., Cincinnati, Ohio

Cleveland Section

Owens, Thurston D., Cleveland, Ohio

Columbus Section

Andrix, Earl R., Columbus, Ohio

Lehigh Valley Section

de May, Charles F., Scranton, Pa.
Man, Shu Sing, S. Bethlehem, Pa.
Porter, Joseph I., Easton, Pa.

Philadelphia Section

Brady, Edward W., Philadelphia, Pa.
Campuzano, George S., Philadelphia, Pa.
Cassel, Daniel E., Philadelphia, Pa.
Forstall, Edward L., Philadelphia, Pa.
Roberts, Carlyle J., Philadelphia, Pa.

Pittsburgh Section

Hodgkins, Charles H., Pittsburgh, Pa.
McVey, Chester L., Pittsburgh, Pa.
Mills, William F., Pittsburgh, Pa.
Thordarson, Steinn D., Brownsville, Pa.
Truex, Ernest H., Woodlawn, Pa.

Toledo Section

Lowery, Wilfred T., Toledo, Ohio
O'Connor, John F., (Member), Toledo, Ohio
Sisterheum, Morris L., Toledo, Ohio

Washington, D. C. Section

Aman, Walter F., Mt. Ranier, Md.
Anderson, Peter N., (Member), Washington, D.C.
Willis, Clodius H., Lignum, Va.

Non-Section Territory

Hurwitz, Abraham A., Hagerstown, Md.
Total 26.

Geographical District No. 3

New York Section

Asset, Henry L., New York, N. Y.
Broadbent, Harold S., Bloomfield, N. J.
Cook, Nicholas, Little Falls, N. J.
Drake, George R., New York, N. Y.
Egner, William F., New York, N. Y.
Englefried, Henry O., Brooklyn, N. Y.
Falk, Leslie A., New York, N. Y.
Frothingham, Donald McL., New York, N. Y.
Goldner, Henry A., New York, N. Y.
Graefenecker, Michael A., New York, N. Y.
Hall, Lawrence M., New York, N. Y.
Haskell, Raymond A., New York, N. Y.
Hatfield, Charles H., Newark, N. J.
Hilbert, Eugene R., Athenai, N. J.
Johnson, Kenneth S., (Member), New York, N. Y.
Lempke, Walter J., New York, N. Y.
Mathis, Charles C., New York, N. Y.
Moritz, Alfred G., New York, N. Y.
McCrum, Walter I., Bloomfield, N. J.
Niessner, Robert J., New York, N. Y.
Pestalozzi, Adolph, New York, N. Y.
Petrella, Anthony G., New York, N. Y.
Rao, Charles, New York, N. Y.
Roberts, Harry A., Brooklyn, N. Y.
Smith, Chauncey, New York, N. Y.
Stokely, Ray, (Member), New York, N. Y.
Weaver, William C., New York, N. Y.
Williamson, Adrian A., (Member), New York, N. Y.

Panama Section

Cordua, Melville L., (Member), Panama, R. P.
Ramires, Luis F., Panama, R. P.
Total 30.

Geographical District No. 4

Atlanta Section

Morgan, Evans, Atlanta, Ga.

Non-Section Territory

Duncan, Josiah C., Knoxville, Tenn.
Frenz, Julius M., Hickman, Ky.
Total 3.

Geographical District No. 5

Chicago Section

Darst, Valentine W., Chicago, Ill.
Smeaton, Charles A., (Member), Chicago, Ill.
Swanson, Carl S., Chicago, Ill.

Indianapolis-Lafayette Section

Canfield, Donald T., W. Lafayette, Ind.
Jones, Walter, New Castle, Ind.

Milwaukee Section

Brown, Charles D., Milwaukee, Wis.
O'Connor, Arthur J., Milwaukee, Wis.

Urbana

Freeland, B. H., Attica, Ind.,

Non-Section Territory

Mitchell, Mortimer G., St. Joseph, Mich.
Stephens, Harley H., Battle Creek, Mich.
Total 10.

Geographical District No. 6

Denver Section

Glezen, Lee L., Denver, Colo.
Kelleher, Clark H., Denver, Colo.
Large, Wayne VanK. Denver, Colo.

Omaha Section

Landgren, Albert V., Omaha, Neb.

Non-Section Territory

Ashe, Irving E., Duluth, Minn.
Hyatt, Ralph S., Valentine, Neb.
Total 6

Geographical District No. 7

Oklahoma Section

Cummings, George W., Muskogee, Okla.

Non Section Territory

Matthews, William H., Pittsburgh, Kansas
Total 2

Geographical District No. 8

Los Angeles Section

Fogwell, Harrison H., Los Angeles, Cal.

Mendenhall, Earl, Los Angeles, Cal.
Schmidt, Walter A., (Member), Los Angeles, Cal.
Yarborough, C. G., Los Angeles, Cal.

San Francisco Section

Johnson, Wayne N., San Francisco, Cal.
Kimball, George E., San Francisco, Cal.
MacQuarrie, Harold C., San Francisco, Cal.
Mullemeister, William, Oakland, Cal.

Non-Section Territory

Wahlstrom, Tom O., Susanville, Cal.
Total 9.

Geographical District No. 9

Portland Section

Hoover, Edgar W., Portland, Ore.

Seattle Section

Brownfield, Ernest S., Tacoma, Wash.
Cunningham, Allan, (Member), Seattle, Wash.
Lamb, L. L., Tacoma, Wash.

Utah Section

Woffington, J. S., Pocatello, Idaho

Non-Section Territory

Marlow, Robert, Montesana, Wash.
Total 6.

Geographical District No. 10

Toronto Section

Frazer, Arthur W., Toronto, Ont.
McLeish, Angus G., Toronto, Ont.
Narrance, Arthur W., Toronto, Ont.

Vancouver Section

Little, John J., Price Rupert, B. C.
McGillivray, Charles A., New Westminster, B. C.

Non-Section Territory

Bishop, Trenholme, A. G., Montreal, Que.
Heeney, Terrence J. C., Montreal, Que.
Total 7.
Total Applications Received 118.

Foreign

Ajani, Francesco, (Member), Milan, Italy
Bagchi, Sudhir K., Jamshedpur, India
Basak, Jagat D., Jamshedpur, India
de Chatelain, Mikail A., Lesnoy, Petrograd, Russia
Faulkner, Arthur S., Brisbane, Queensland, Aus.
Kemp, Philip, London, Eng.
Mitchell, John H., Hull, Eng.
Newman, Horace S., Hanley, Stoke-on-Trent, Eng.
Nissen, Jacob P., Kristiania, Norway
Welsford, Douglas, London, Eng.
Wrigley, Albert E., Matamata, N. Z.
Total 11.

STUDENTS ENROLLED MAY 19, 1922

14994 Klaproth, William O., Univ. of Illinois
14995 Ennis, Frederick J., Drexel Institute
14996 Vouch, Stephen J., Worcester Poly. Inst.
14997 Torrey, William F., Jr., Wentworth Inst.
14998 Ladd, James R., Oregon Agri. College
14999 Asofsky, Isaac, Cooper Union
15000 DeRanzis, Joseph, Cooper Union
15001 Geis, Harold W., Cooper Union
15002 Hebling, Albert G., Cooper Union
15003 Papacek, Frank, Cooper Union
15004 Milliken, Warren T., Cooper Union
15005 De laVergne, W. Harold, Catholic University of America
15006 McCabe, Henry L., Catholic University of America
15007 Boyer, David A., Carnegie Inst. of Tech.
15008 Wood, Richard H., Ohio State University
15009 Steans, Kenneth R., Worcester Poly. Inst.
15010 Higdon, James J., Georgia School of Tech.
15011 Carter, Homer M., Georgia School of Tech.
15012 Hoefer, Charles R., Stevens Inst. of Tech.
15013 Karcher, John E., Mass. Institute of Tech.
15014 Northam, Lawrence E., Tri-State College of Engineering
15015 Freeman, Aaron, Johns Hopkins Univ.
15016 Taylor, William P., Johns Hopkins Univ.
15017 Wells, Ben. F., University of Kansas
15018 Seymour, Murray M., Johns Hopkins Univ.
15019 Warner, Norwood A., New Hampshire Coll.
15020 Zwiedom, E. A. Alvin, University of Texas
15021 Lewis, Ervin H., Northeastern College
15022 Corrado, Anthony, Lewis Institute
15023 Perlstein, Philip, Brooklyn Poly. Institute
15024 Coulter, Stanley L., University of Toronto
15025 Boothby, Clinton R., University of Maine
15026 See, W. Howe, Worcester Polytechnic Inst.
15027 Robertson, Archibald F., Mass. Institute of Technology
15028 Kelly, John M., Carnegie Institute of Tech.
15029 Eskil, William A., Pratt Institute
15030 Irwin, William A., Pratt Institute
15031 French, George B., Pratt Institute
15032 Kleinert, Paul F., Pratt Institute
15033 Dickinson, Otis, Pratt Institute
15034 Ferguson, Floyd F., Pratt Institute
15035 Homan, Charles W., Pratt Institute
15036 Steinbach, Frank, Pratt Institute
15037 Schenck, Romeyn P., Pratt Institute
15038 Menzel, Arthur F., Pratt Institute
15039 Potts, Julian, Pratt Institute
15340 Lear, William H., Pratt Institute
15041 Langan, William J., Pratt Institute
15042 Clark, Frederick A., Pratt Institute
15043 Finn, James J., Pratt Institute
15044 Raznik, Emanuel E., Pratt Institute
15045 Marshall, Joseph A., Pratt Institute
15046 Wyrtzen, Curtis C., Pratt Institute
15047 Proctor, Joseph W., Jr., Pratt Institute
15048 Price, William H., Pratt Institute
15049 Simpson, William O., Pratt Institute
15050 Rogers, Warren O., Pratt Institute
15051 Keener, Jacob, Lewis Institute
15052 Schlather, Erich G., A.&M. College of Tex.
15053 Kelly, Joseph G., Marquette University
15054 Reitmeyer, William B., Marquette Univ.
15055 Hunt, George B., Marquette University
15056 Kohler, Harry W., Marquette University
15057 Ruesch, Arthur B., Marquette University
15058 Johnson, Wesley O., Marquette University
15059 Rumrill, Hamilton, Lowell Institute
15060 Mattison, Walter W., Lowell Institute
15061 Cowles, Eustace E., Penn. State College
15062 Cockburn, John M., Queen's University
15063 Costenoble, Erich H., Drexel Institute
15064 Currier, Preston, H., New Hampshire State College
15065 Thomas, Richard R., Montana State Coll.
15066 Looney, Texas, Oklahoma A. & M. College
15067 Lancaster, Elon F., Northeastern College Engg. School
15068 Suhr, Herbert F., Marquette University
15069 Elliott, Walter, Tri-State Coll. of Engg.
15070 Smith, William G., Washington University,
15071 Lefever, Paul M., Tri-State Coll. of Engg.
15072 Churchill, Colin F., North Carolina State College
15073 Hunt, Leonard G., Univ. of Illinois
15074 Coleman, John B., Carnegie Inst. of Tech.
15075 Cary Alvin C., Cooper Union
15076 Fishell, Marion F., Washington University
15077 Higgs, Percival J., Mass. Inst. of Tech.
15078 Goddard, Loren R., Pratt Institute
15079 Terhune, Wallace I., Pratt Institute
15080 Halbrook, James H., Pratt Institute
15081 Farmer, William J., Pratt Institute
15082 Brownell, Frank A., Pratt Institute
15083 Hartmen, Howard W., Pratt Institute
15084 Dulack, Edmund F., Pratt Institute
15085 Domery, John C., Jr., Rensselaer Poly. Inst.
15086 Bowlen Wayne F., Montana State College
15087 Ashbaugh, Frederic A., Carnegie Inst. of Technology
15088 Leary, Wilfred J., Montana State College
15089 Connell, Joseph A., Univ. of Pittsburgh
15090 Lander, David H., University of Pittsburgh
15091 Marshall, Alvin J., Univ. of Pittsburgh
15092 Marshall, Robert P., Univ. of Pittsburgh
15093 Miller, Warren W., Univ. of Pittsburgh
15094 Moore, Francis G., Univ. of Pittsburgh
15095 Maish, Edward A., Univ. of Pittsburgh
15096 Raring, William H., Univ. of Pittsburgh
15097 Robert, Arthur F., Univ. of Pittsburgh
15098 Robinson, William H., Univ. of Pittsburgh
15099 Ward, William C., Univ. of Pittsburgh
15100 Zinsser, Alfred H., Univ. of Pittsburgh
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Portland, Ore.	W. C. Heston	D. W. Proebstel, Portland Ry. Lt. & Pr. Co., Portland, Ore.
Providence	Nicholas Stahl	F. N. Tompkins, Brown Univ., Providence, R. I.
Rochester	Sidney Alling	A. M. Stetler, Aluminum Co. of America, Granite Bldg., Rochester, N. Y.
St. Louis	C. C. Robinson	J. M. Chandler, 1827 Pine St., St. Louis, Mo.
San Francisco	W. P. L'Hommedieu	A. G. Jones, 809 Rialto Bldg., San Francisco, Cal.
Santiago de Chile	———	———
Schenectady	S. H. Blake	C. W. Fick, General Electric Co., Schenectady, N. Y.
Seattle	J. P. Growdon	E. S. Code, 3451 E. Marginal Way, Seattle, Wash.
Southern Virginia	———	———
Spokane	L. J. Pospisil	H. L. Melvin, Washington Water Power Co., Spokane, Wash.
Syracuse	E. T. Moore	Elmer E. Strong, 614 City Bank Bldg., Syracuse, N. Y.
Toledo	G. Southern	Max Neuber, 1257 Fernwood Ave., Toledo, O.
Toronto	W. P. Dobson	P. A. Borden, 8 Strachan Ave., Toronto, Ont.
Urbana	E. H. Waldo	H. A. Brown, Univ. of Illinois, Urbana, Ill.
Utah	P. P. Ashworth	C. R. Higson, Utah Power & Light Co., Salt Lake City, Utah
Vancouver	John R. Read	F. W. McNeill, Canadian General Elec. Co., Vancouver, B.C.
Washington, D. C.	A. R. Cheyney	W. A. E. Doying, Panama Canal Commission, Washington, D.C.
Worcester	G. M. Hardy	Dean J. Locke, 125 Salisbury St., Worcester, Mass.

Total 46

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Arkansas, Univ. of, Fayetteville, Ark.	J. W. Booker	B. R. Askew
Armour Inst. of Tech., Chicago, Ill.	R. P. Burns	L. E. Grube
Brooklyn Poly. Inst., Brooklyn, N. Y.	H. Ladner	O. Engstrom
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Clarkson Coll. of Tech., Potsdam, N.Y.	R. L. Conboy	F. H. Fults
Clemson Agri. College, Clemson College, S. C.	J. R. Reardon	W. M. Clatworthy
Colorado State Agri. Coll., Ft. Collins, Colo.	P. Garrett	F. Ayres
Colorado, Univ. of, Boulder, Colo.	T. D. Sylvester	F. B. Doolittle
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Iowa, Univ. of, Iowa City, Ia.	E. Paintin	P. F. Bowman
Kansas State College, Manhattan, Kans.	L. O. Sinderson	K. C. Frank
Kansas, Univ. of, Lawrence, Kans.	E. S. Miner	C. A. Harris
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Lewis Institute, Chicago, Ill.	E. Millison	E. R. Lindberg
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Texas, Univ. of, Austin, Tex.	C. H. Marshall	F. J. Domingues
Virginia Military Inst., Lexington, Va.	W. P. Venable	R. P. Martin
Virginia Poly. Inst., Blacksburg, Va.	D. P. Minichan	T. F. Cofer
Virginia, Univ. of, University, Va.	M. H. Morgan	N. W. Brown
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West Virginia Univ., Morgantown, W. Va.	H. Chandler	W. D. Stump
Wisconsin, Univ. of, Madison, Wis.	R. H. Herrick	J. W. Smart
Yale Univ., New Haven, Conn.	E. R. Zeitz	S. S. Bailey

Total 68

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGS AND OTHER TRADE PUBLICATIONS

Mailed to interested readers by issuing companies.

Industrial Lighting Briefs.—A series of articles, which will be published from time to time, on industrial lighting problems. Cooper Hewitt Electric Co., Hoboken, N. J.

Oil Coolers.—Bulletin No. 904. 16 pp. Describes oil cooling system for large Diesel engines. The Griscom-Russell Co., 90 West St., New York.

Insulating Material.—Bulletin 6 pp., describing various grades of "Fibro" insulation manufactured by the Fibroc Insulation Co., Valparaiso, Ind.

Ball Bearings. Book 70 pp. "Ball Bearings for Electrical Machinery." Illustrates the application of ball bearings in numerous types of rotating electrical apparatus. SKF Industries, Inc., 165 Broadway, New York.

Switchboards and Panelboards.—Catalog, 1922; 90 pp. Contains specifications, wiring diagrams and a special section devoted to stage and auditorium lighting control. Mutual Electric & Machine Co., Detroit.

Circuit Breakers.—Bulletin, 16 pp. Describes a variety of remote control circuit-breakers of both motor and magnetically operated types, together with other forms of apparatus especially adapted to central station requirements. The Cutter Company, Philadelphia.

Printing Press Drive and Control.—Bulletin 48717, 16 pp. Describes the Sprague System of electric motor drive and control for newspaper presses; also specialties applicable in composing room and jobbing department. Sprague Electric Works of G. E. Co., 527 W. 34th St., New York.

Filament Rheostats.—Bulletin. Describes the "Bradleystat" for regulating the voltage or current to the filaments of vacuum detectors, amplifiers or transmitting tubes. The devices make use of the graphite compression principle, wherein the resistance is varied through pressure applied to a column of graphite discs. Allen-Bradley Co., Milwaukee.

Belted Type Alternators.—Bulletin 1099B, 12 pp. Describes Types "AB" and "AH" belted alternating current generators. The former class are made only in the smaller sizes and up to 300 kv-a., while the "AH" type can be supplied in any size, the limit being determined solely by the practicability and economy of using a belt or rope drive. Allis Chalmers Mfg. Co.. Milwaukee.

Instructions for Making Radio Set.—Circular of the Bureau of Standards. No. 120, entitled "Construction and Operation of a Simple Home-Made Radio Receiving Outfit." The construction of a very simple radio receiving equipment for communication on wave lengths between 600 and 200 meters from high-power stations within fifty miles is described. Directions for operation are also given. The total cost of material used in such a set need not exceed $10. Copies of the circular (16 pp.) may be obtained by sending five cents to the Superintendent of Documents, Govt. Printing Office, Washington, D. C.

Power Factor Correction Condensers.—Bulletin 1. Describes a line of static condensers for the correction of power factor which can be applied directly to individual motors. The advantages claimed for this apparatus are low first cost; flexibility, so as to be applicable in large and small systems equally well; and capacity to correct the power factor of individual motors, which in turn will correct the power factor of an entire generating and distributing system. These condensers are manufactured under the Segal patents of the Societe Anonyme des Condensateurs de Trevoux (Ain) France by the National Electric Condenser Company, New Haven, Conn., the officers of which are V. M. Tyler, Pres., L. S. Horner and L. S. Tyler, Vice-Pres., and Brower Hewitt, Treas. This company is owned by the Acme Wire Company, also of New Haven.

CHANGES IN THE INDUSTRY; NEW APPARATUS

The Wagner Elec. & Mfg. Co., St. Louis, has moved its Salt Lake City Office to 313 Dooly Building.

The High Tension Insulator Corporation, Ballston Spa, N. Y., has been organized for the production of moulded insulators and parts.

The Bristol Company, Waterbury Conn., has perfected a sound amplifier for use in connection with radio apparatus, called the Audiphone or Loud Speaker.

The Bristol Company, Waterbury Conn., Recording Instruments. A new branch office has been opened at Philadelphia, Room 1311 Widener Building. C. C. Eagle, Jr., formerly in charge of the Detroit office, is sales representative.

Harvey Hubbell, Inc., Bridgeport, Conn., announces the recent election of Harry W. Bliven as Vice-President of the company. Mr. Bliven has been General Sales Manager of the company for more than twenty years, and as Vice-President is to continue in charge of sales.

Jeffery-Dewitt Insulator Company, Kenova, W. Va. The main sales office has been removed to 50 Church Street, New York. Mr. Raymond W. Lillie has been made General Sales Manager, and a Vice-President. It is reported that the volume of sales has been increasing rapidly since January 1, and that the production this year should be 400.000 insulators.

The First National Industrial Advertising Conference will be held at Milwaukee, June 11-15, in connection with the A. A. C. of W. Convention. The problems encountered in selling materials and equipment will be discussed, and a number of papers on the selling of technical products are to be presented. It is expected that many electrical manufacturers will be represented at the conference. Programs and other details may be obtained from Keith J. Evans, Chairman, 16th & Rockwell Sts., Chicago.

The Brown Instrument Company, Philadelphia, has placed on the market a new direct-reading resistance thermometer, for use in any process where the temperature must be known throughout with extreme accuracy and maintained constantly within close limits. Among suggested applications where the device can be used to advantage are in power plants for many temperature measurements, for the temperature of coal piles to prevent spontaneous combustion, in chemical processes for the approach of anchor ice temperatures in hydroelectric power plants in public buildings, and numerous other uses.

The Manufacturers Electrical Corporation, 123 W. Madison St., Chicago, has been organized to act as exclusive Middle West representative for a number of manufacturers of electrical equipment, including domestic appliances, switching equipment, circuit-breakers, wiring specialties, transformers, noulded insulation, wire and cable and other apparatus, and is prepared to take over the sale and distribution of such equipment for manufacturers in the territory specified. Edgar Switzer, who has been syndicate representative of the Westinghouse Elec. & Mfg. Co., in its Chicago office territory, has resigned his position to become Vice-President and General Manager of the new company.


KERITE-
TIME—FACTS—
CUMULATIVE EXPERIENCE
roll up the Record
of its
Unequalled Service
DAYS KERITE
KERITE INSULATED WIRE & CABLE COMPANY
NEW YORK CHICAGO
Ellibridge 60-232

moisture beads are no longer in evidence. The contents of the tank should then be allowed to settle from [illegible]everal hours to a day before a test sample is drawn. Such a sample will more certainly indicate the entrai[illegible]d moisture, which is the important thing, as the [illegible]resence [illegible] very small quantities of water will grea[illegible] low[illegible] insulating value of the oil and likewis[illegible] [illegible]ture point.

L. [illegible]RDIN,
Elec[illegible] Engineer.

Mees & Mees, Consulting Engineers,
Charlotte, N. C.

Closed-Circuit Ventilating System for Cooling Turbo-Generator

TO PREVENT generator fires arising from the deposition of dust in the ventilating ducts, the closed-circuit system of generator cooling has been adopted for the Fairmont (W. Va.) station of the Monongahela Power & Railway Company, the same air being used over and over again. This system was considered necessary because in the coke-oven and blast-furnace districts of Pennsylvania and West Virginia the atmosphere carries an unusually large content of sooty byproducts of the ovens.

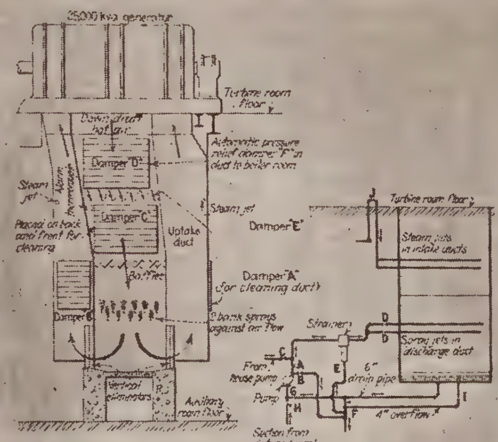
To obtain an idea of the volume of impurities encountered in this district consider the air used in cooling a generator of 25,000-kva. capacity. The generator fans draw 50,000 cu.ft. of air per minute, which, taken over a period of twenty-four hours, weighs approximately 5,500,000 lb. About two cubic feet of impurities would be carried in this amount of air. With the old scheme of air washing, using a continuous blast of air from outdoors, if the washer removes 98 per cent of the impurities, three or four cubic feet of dirt would pass into the generator in three months of operation, much of which would be deposited in the ventilating spaces. These figures are borne out by experience gained in cleaning generators equipped with older schemes of air washing. This accumulation of dirt is very often the cause of generator fires.

In the installation of the air-cooling apparatus, built by the Spray Engineering Company, in this plant

vented. Con[illegible]uently it was decided to use a closed air circ[illegible]simply cooling and humidifying and contin[illegible] repassing only one volume of air through the [illegible]rator. No outside air with its content of dirt is [illegible]sed, and obviously the cooling air can pick up no new dirt after passing through the sprays.

The relative positions of the dampers, baffles and air passages are shown on the left of the accompanying illustration. A long period of thorough contact between the hot air and mist is secured by arranging the sprays to discharge against the flow of air in a vertical direction, thus increasing the efficiency of heat removal and rehumidifying. The arrangement of eliminators in a vertical position is the most effective possible. Above the sprays a series of baffles is used to prevent a jet of water from reaching the generator laminations directly above, in case of breakage of a spray head.

In removing the heat from the air that has been carried away from the windings and laminations water is



CLOSED-CIRCUIT COOLING SYSTEM FOR GENERATORS IN SOOTY DISTRICTS PREVENTS DIRT FROM ENTERING MACHINES

Left—Air-cooler arrangement showing locations of dampers. Dampers *A*, *B*, *C*, *D* and *F* open to atmosphere for cleaning, repairing, etc. *E* is across the discharge duct to prevent circulation of air during an emergency. In case of steam being used for fires, damper *F* automatically opens to relieve internal pressure.

Right—Water-piping system for cooling air. Valves *A* and *D* control sprays. *B* is used for discharge during high water. *C* is for emergency. *E* is a quick opening to clean strainer. *F* is a 6-in. drain closed during flood. *G* a 6-in. drain opened to use [illegible] against head. *H* is in the pump suction line. *I* is a 4-in. [illegible] closed in flood to prevent back water, and *J* is [illegible] for fire control.

OPERATING INSTRUCTIONS FOR AIR AND WATER SYSTEMS FOR TURBO-GENERATOR COOLER

IMPORTANT MEMO:--

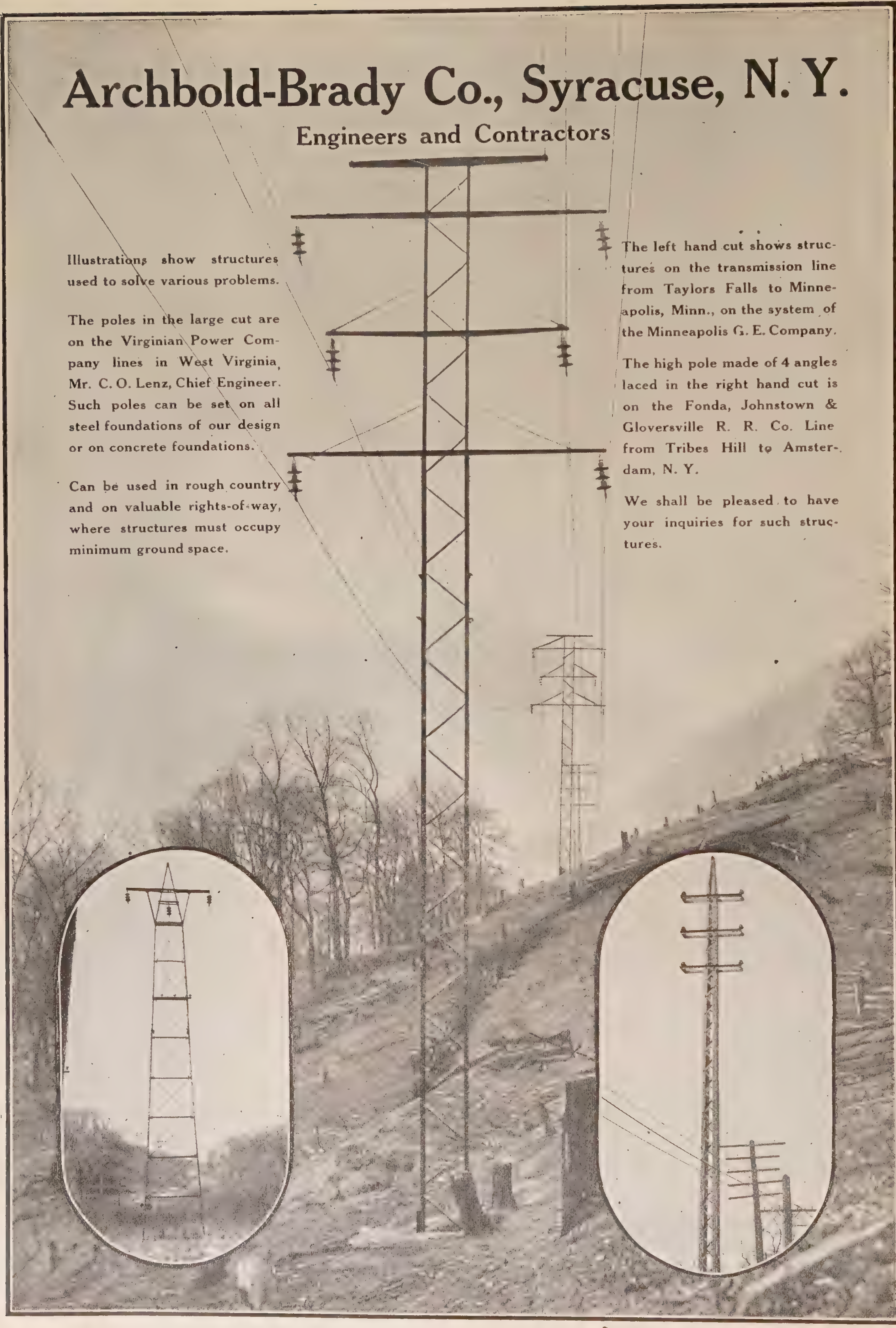
Write Spray Engineering Co--60 High St. Boston, Mass--for a reprint of this article (Closed-Circuit Ventilating System for Cooling Turbo-Generator") which appeared in April 15th issue of "Electrical World."

[illegible]ter-discharge tun[illegible]rculating pump of [illegible]xternal head, since [illegible]lood level, and the [illegible]n the house-service [illegible]om the condensing- [illegible] the air discharged [illegible] a Brown indicating [illegible], as indicated in the [illegible] An alarm contact [illegible]ature reaches a dan[illegible]tchboard temperature [illegible] operators of any un[illegible]chment may be easily [illegible]peratures to ascertain

the designers [illegible] preventing the accumulation of dirt as [illegible] creasing the reliability of the unit, which has a capacity of 25,000 kva. The cost of pumping cooling water for the sprays and the loss of generator heat, which is not recovered, is of minor importance if fires can be pre-

[illegible] that it is operating [illegible]

It is believed that the chief cause of fires has been overcome by this arrangement, but should any condi-


Archbold-Brady Co., Syracuse, N. Y.
Engineers and Contractors
Illustrations show structures used to solve various problems.
The poles in the large cut are on the Virginian Power Company lines in West Virginia, Mr. C. O. Lenz, Chief Engineer. Such poles can be set on all steel foundations of our design or on concrete foundations.
Can be used in rough country and on valuable rights-of-way, where structures must occupy minimum ground space.
The left hand cut shows structures on the transmission line from Taylors Falls to Minneapolis, Minn., on the system of the Minneapolis G. E. Company.
The high pole made of 4 angles laced in the right hand cut is on the Fonda, Johnstown & Gloversville R. R. Co. Line from Tribes Hill to Amsterdam, N. Y.
We shall be pleased to have your inquiries for such structures.

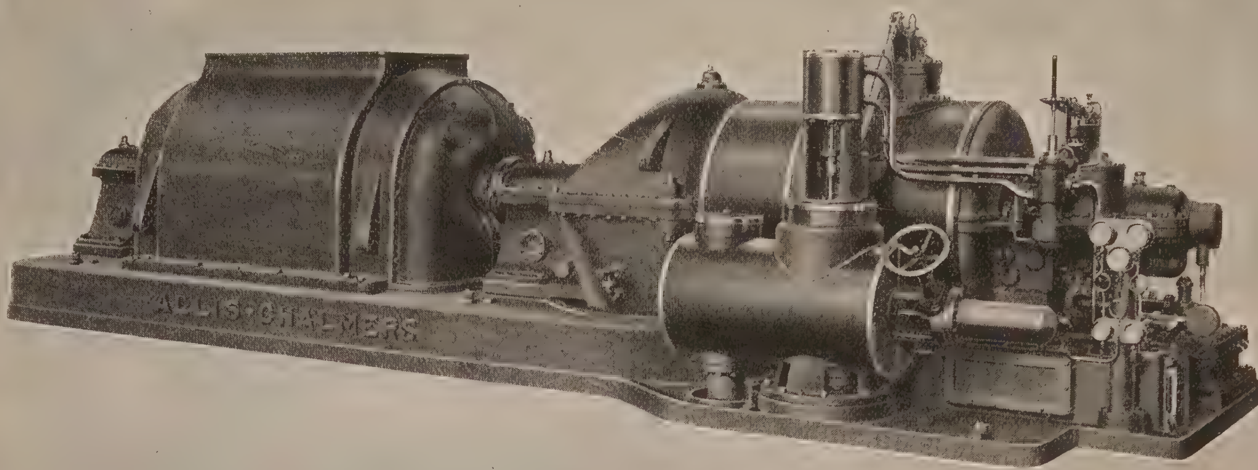
PAGE AND HILL CO.

MINNEAPOLIS, MINN.

Times Bldg., New York, N.Y.
1111 Carter Bldg., Houston, Tex.

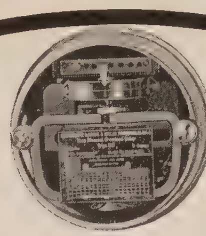
717 Bryant Bldg., Kansas City, Mo.
311 Sumpter Bldg., Dallas, Tex.

19 S. La Salle, Chicago, Ill.
1416 Starks Bldg., Louisville, Ky.

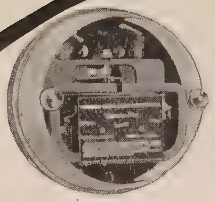


Westinghouse Relays

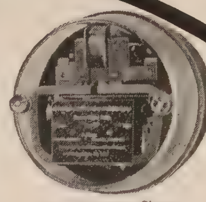
A Complete Line



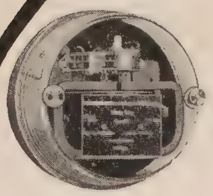
Type CO Overload Relay



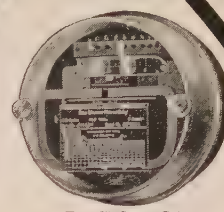
Type CT Temperature Relay



Type CP Reverse-Phase Relay



Type CV Voltage Relay



Type CW Power Relay for A.C. Circuits

Westinghouse Relays are the most accurate and reliable means known for obtaining the following results:

Protection of electric-power equipment from short circuits and grounds.

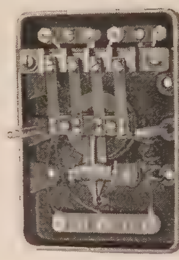
Prevention of interruptions in service and costly shutdowns due to line troubles.

Efficient loading of transmission lines and distribution feeders.

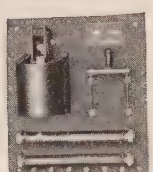
To obtain these results the expense of installing Westinghouse Relays on your system is fully justified.

This complete line of Westinghouse Relays is described in detail in the Westinghouse Catalogue of Electrical Supplies on pages 643 to 660 inclusive.

Type CR Reverse Power Relay

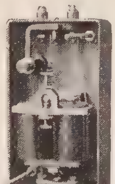


Type M Multiple-Contact Auxiliary D.C. Relay.



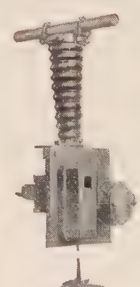
Type R Service Restoring Relay

Type KN Signal and Trip Free Relay



Type TO Overload Relay D.C.

Type D Reverse-current Overload and Temperature Relay, D.C.



Type CB Overload Relay

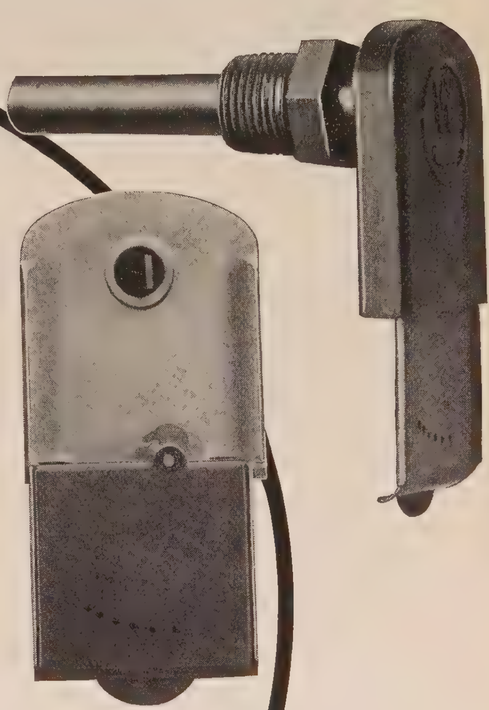
Cycle counter for measuring time of operation of relays

Westinghouse Electric & Manufacturing Company
Newark Works, Newark, N. J.

Westinghouse

ANNOUNCING

The Westinghouse Transformer Load Indicator



Arranged for mounting in the drain plug of a distribution transformer, the Westinghouse Transformer Load Indicator provides a ready means of detecting an overloaded or an underloaded transformer.

The indication is given by a yellow semaphore which has a surface of 2½ square inches and which can, therefore, be readily seen from the street by the patrolman.

The semaphore is released when the predetermined temperature is reached or exceeded. The indicator can be set to trip the semaphore at any desired temperature from 50° to 100° C.

The construction of the Westinghouse Transformer Load Indicator has been kept as simple as possible consistent with a high degree of reliability, to permit its general use on the hundreds of thousands of distribution transformers in service.

It is Accurate in Calibration
Reliable in Operation
Simple to Install

The Westinghouse Transformer Load Indicator fills a long-felt need in the efficient application and overload protection of distribution transformers.

Leaflet 3437 gives full particulars, copy mailed upon request.

Westinghouse Electric & Manufacturing Company
East Pittsburgh, Pa.

Westinghouse

Some Users of Acme Magnet Wire

Auth Electrical Specialty Co.
Century Electric Co.
Connecticut Telephone & Electric Co.
Crocker-Wheeler Co.
Dayton Engineering Laboratories Co.
Delco Light Co.
Diehl Manufacturing Co.
Domestic Electric Co.
Eiseman Magneto Co.
Electric Specialty Co.
Electrical Products Manufacturing Co.
Eureka Vacuum Cleaner Co.
Ford Motor Co.
Gray & Davis, Inc.
Holtzer-Cabot Electric Co.
Hoover Suction Sweeper Co.
Klaxon Co.
Remy Electric Co.
Robbins & Myers Co.
Sangamo Electric Co.
U. S. Auto Supply Co.
Ward Leonard Electric Co.
Westinghouse Electric & Manufacturing Co.
Willys Corporation.

Acme Wire Products Include

"Enamelite," plain enameled Magnet Wire; "Cottonite," Cotton-covered Enamelite; "Silkenite," Silk-covered Enamelite; Single and Double Cotton Magnet Wire; Single and Double Silk Magnet Wire. We also have a complete organization for the winding of coils in large production quantities.

ACME

Brown's coil output increased 20%

Joe Brown is a winder in an automobile plant. One day his foreman brought him some new wire. "They want us to try this out, Joe," he said.

Joe slipped a spool into his machine and went to it. By the end of the week they found his output of perfect coils had jumped 20%.

"How do you account for it, Joe?" they asked him. "Why," said the winder, "this new stuff *goes in the space.*"

The "new stuff" was Acme Wire.

* * *

What that operator meant was that Acme Wire is so uniform, so perfectly insulated, and so free from lumps and imperfections, that more coils could be wound with it in a given time—and a higher percentage of perfect coils—than with wire that does not have such high *winding efficiency*.

For Acme Wire is made to wind easily, swiftly, and without having to stop the machine to hammer down or to replace imperfect wire. We wind hundreds of thousands of coils every year in the Acme plant; we know the problems of the winding room, and have worked for years to solve them.

This factor of *low-cost winding* is just as important as *high-quality material;* for many a low-priced wire becomes extremely expensive in the end, through its poor winding quality. Naturally, there has been a tendency to overlook this particular phase of magnet wire during the last few years, in the rush for production at any cost.

But today, manufacturers who are seeking in every way to reduce costs, or to make better goods at no greater cost, are investigating the winding efficiency of wire, and we have many instances on record where savings of 20% to 30% have been effected through the use of Acme Wire, chiefly because Acme Wire *goes in the space.*

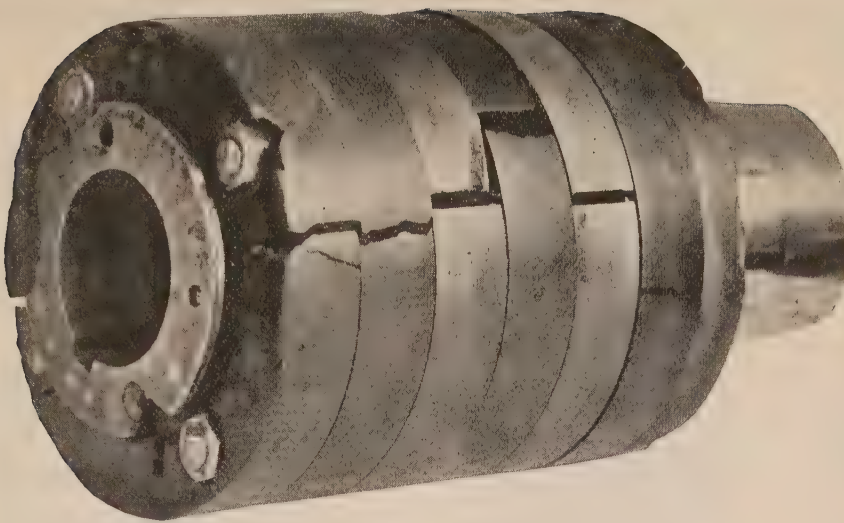
Purchasing Agents who keep in close touch with their winding departments, as well as engineers who work out specifications and cost figures on coils and windings of all sorts, find that it pays to use Acme Wire—for its high quality of copper and insulation, and its exceptional economy on the winding machine.

Our new illustrated catalog will be sent to Engineers and Purchasing Agents on request

THE ACME WIRE CO., New Haven, Conn.
NEW YORK CLEVELAND CHICAGO

Acme Wire

"It goes in the space"



he ordered—

A ROCKWOOD PAPER PULLEY

—to replace it!

THE *final* pulley on a motor is usually a Rockwood Paper Pulley. When *other* pulleys fail—whether it be from structural defects or from poor transmitting capacity—then the user turns to ROCKWOOD for *pulley service.*

This user bought and paid for a special wood pulley for his motor—but it failed. He has ordered a Rockwood Paper Pulley to *replace* it. And now his pulley troubles are over.

Possibly in your plant you, too, have unsatisfactory motor pulleys that should be replaced with Rockwood Paper Pulleys.

THE ROCKWOOD MANUFACTURING Co
ROCKWOOD'S
PAPER PULLEY
KEEP CLEAN DRY
INDIANAPOLIS, INDIANA, U.S.A.

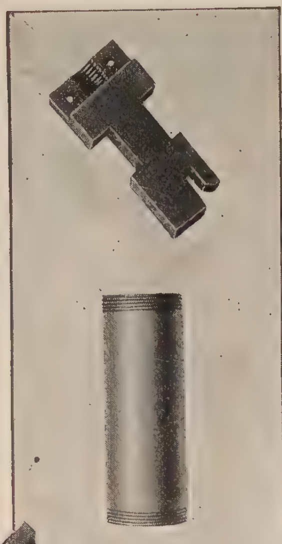
THE ROCKWOOD MFG. COMPANY
PAPER
ROCKWOOD
PULLEY
INDIANAPOLIS, INDIANA, U.S.A.

See that the pulleys you buy bear one of the Rockwood Labels.

THE ROCKWOOD MFG. COMPANY 1947 English Avenue., Indianapolis, U.S.A

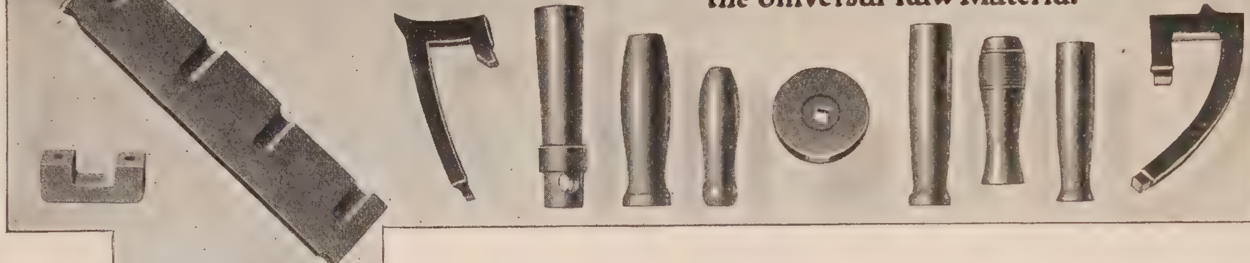
All the Power—All the Time

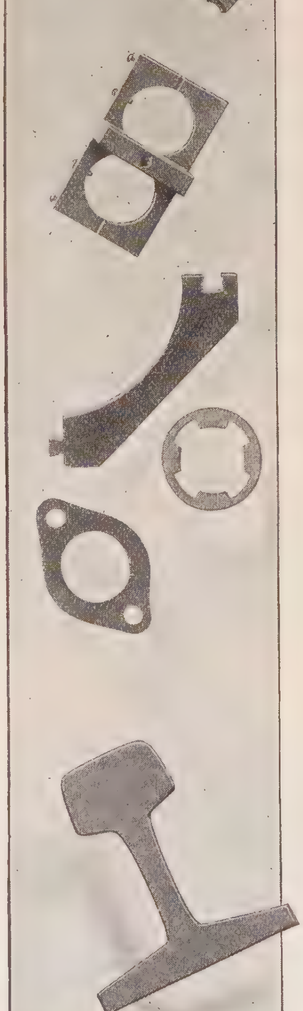
ROCKWOOD PULLEY SERVICE



Are You Alive to the Facts that

Diamond Fibre
the Universal Raw Material





has a tensile strength of from 12,000 to 15,000 lbs.—a compressive strength of 25,000 lbs.—and a shearing strength of 10,000 lbs. to the square inch?

Do you realize that this remarkable material is almost as strong as iron, yet lighter than aluminum?

Are you aware that it is rustless, splinterless, highly dielectric and practically indestructible?

Do you know that it is adaptable to every machining process, may be bent or formed into almost every conceivable shape and will take any finishing process?

Do you know that you can obtain Diamond Fibre in standard sheets, rods and tubes—in practically every color—and every degree of hardness from rigid to flexible? Or, that we will machine it to your specifications?

Are you aware that this material has been used for years in the manufacture of thousands of products?

All of these facts lead to one thought. Perhaps you have overlooked this labor saving, cost reducing, universal raw material. Find out all about it now. Write us—tell us what you make—and let us get together. Maybe we can suggest something that will be mutually advantageous.

Diamond State Fibre Company

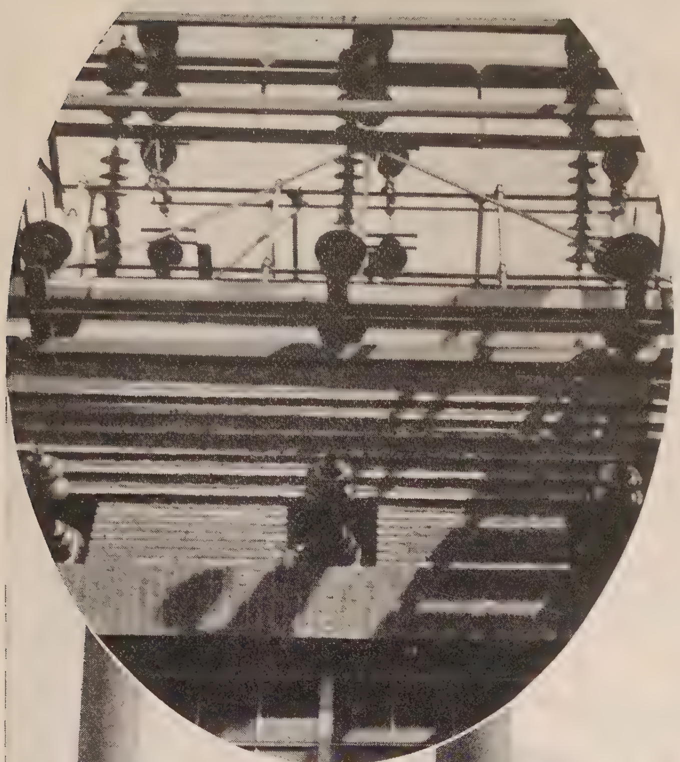
Bridgeport (Near Philadelphia) **Penna.**

Branch Factory and Warehouse, Chicago

Offices in Principal Cities

In Canada: **Diamond State Fibre Company of Canada, Ltd., Toronto**

Putting a three dimensioned job on O-B Insulators

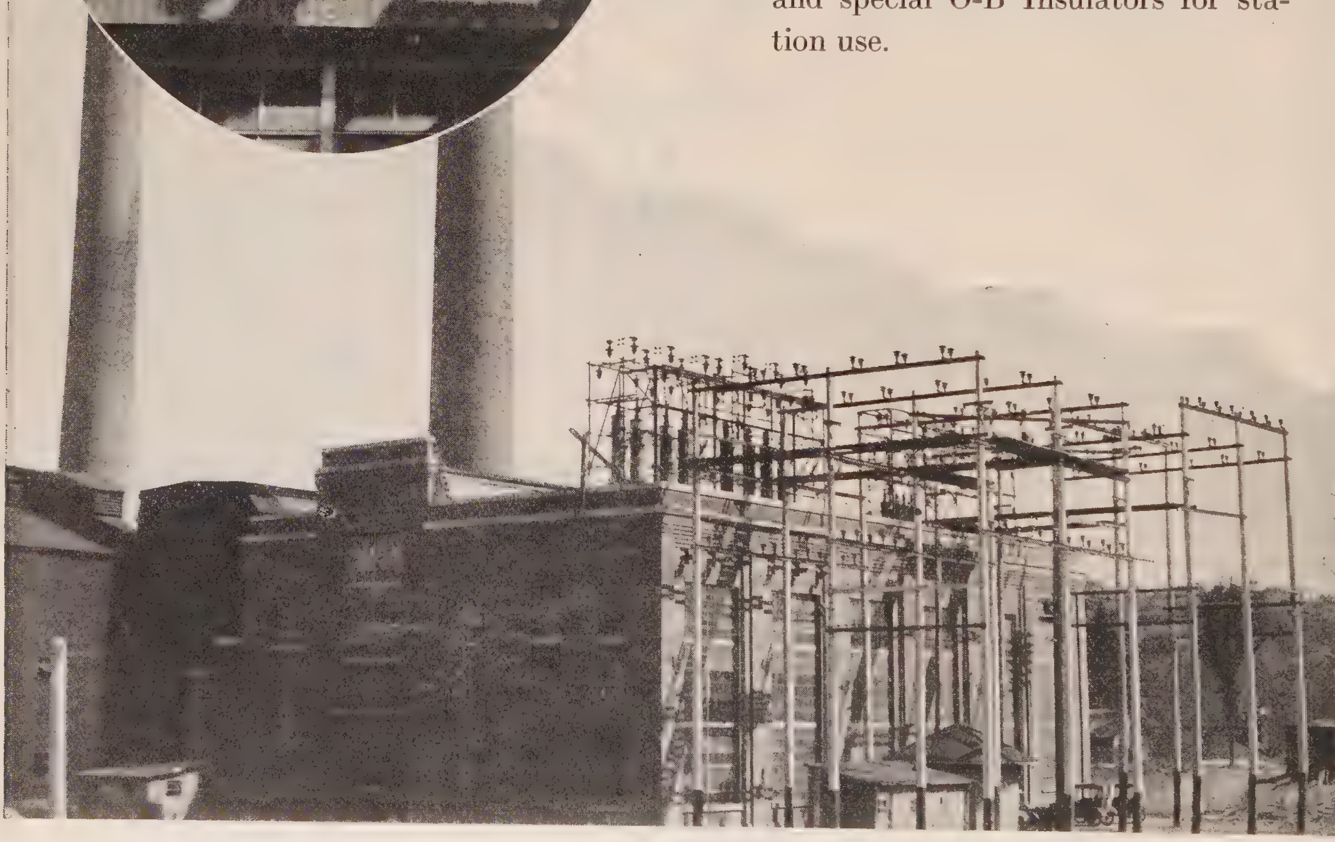


Besides electrical insulation there are two other important functions which O-B Station Insulators perform well.

One of these is the mechanical strain which is often severe—at least momentarily.

And the other thing that O-B Insulators do well is FIT. Particular care is taken in designing O-B Station Insulators to keep them compact and in assembling them to follow exact specifications.

There is a large variety of standard and special O-B Insulators for station use.

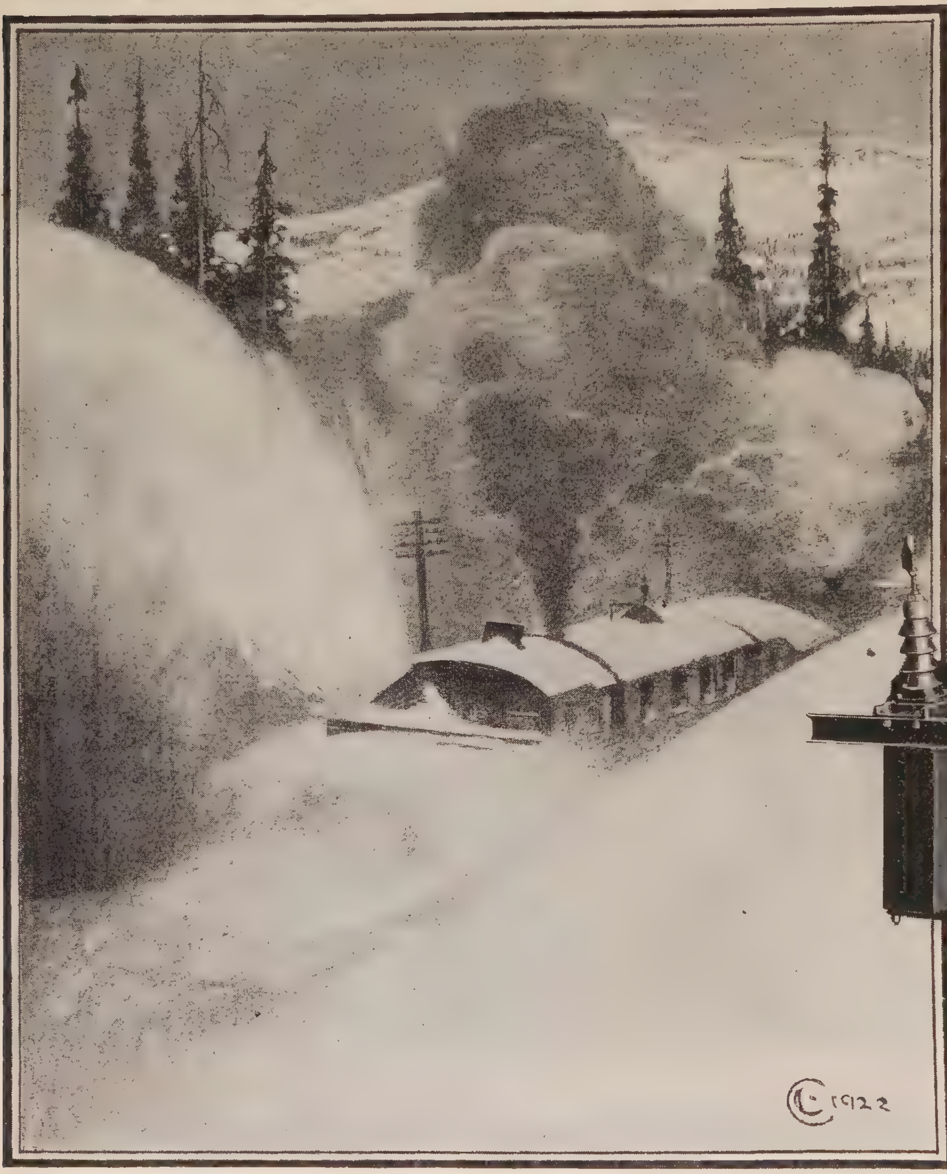


The Ohio Brass Co.
Mansfield, Ohio, U.S.A.

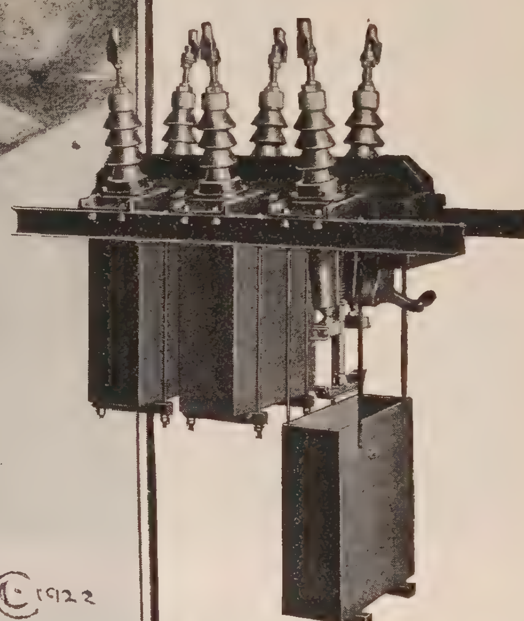
New York Philadelphia Pittsburgh Charleston, W Va. Chicago Los Angeles San Francisco Paris, France

Products: Trolley Material, Rail Bonds, Electric Railway Car Equipment, High Tension Porcelain Insulators, Third Rail Insulators

Clear the Line!



CONDIT O-1
Outdoor
Oil Circuit Breaker



As the powerful railroad snow plow clears the line when traffic is blocked by winter drifts—so does the rugged, dependable construction of the CONDIT Type O-1 Outdoor Oil Circuit Breaker enable you to clear your transmission and distribution lines—sectionalize your system—isolate trouble—when emergency hits your overhead. Conservatively designed, sturdily built, weatherproof, the CONDIT Type O-1 is a switch on which you can equally rely to withstand the attacks of storm and sleet, and the stresses of opening high power circuits.

SPECIFICATIONS:

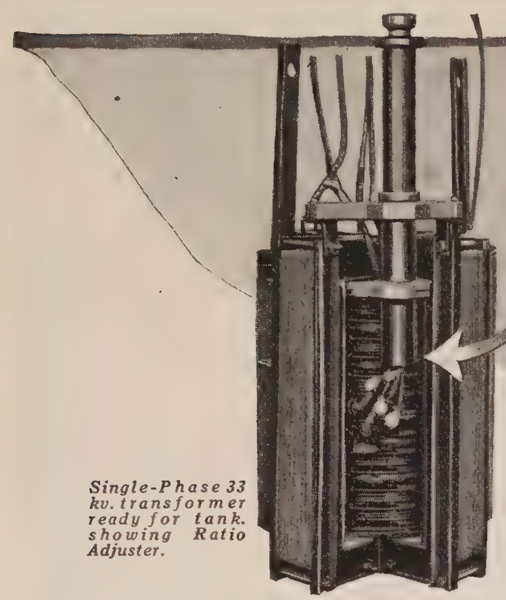
15,000 and 25,000 Volts up to 600 Amperes. Self-contained, tripping transformers for automatic operation. Manually or electrically operated.

CONDIT ELECTRICAL MFG. CO.
Manufacturers of Electrical Protective Devices
BOSTON 27, MASS.
Northern Electric Company
LIMITED
Sole Distributor for the Dominion of Canada

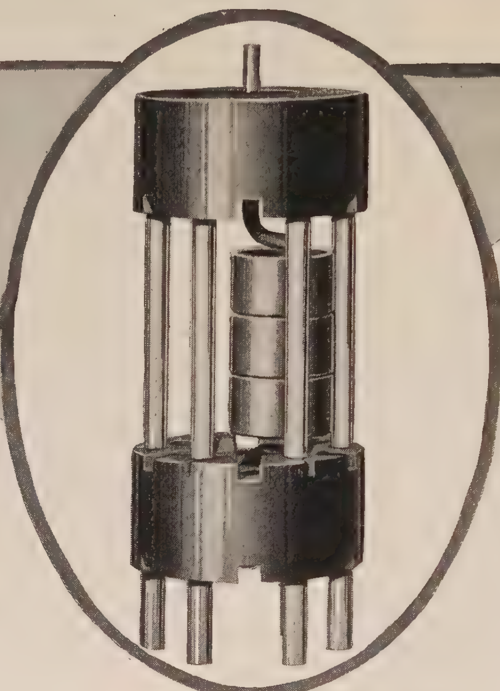
122-47

CONDIT

The Most Convenient Accessory Ever Added to a Transformer



Single-Phase 33 kv. transformer ready for tank. showing Ratio Adjuster.



Ratio Adjuster Contact Unit.

Ratio Adjuster Complete.

Transformer Ratio Adjuster

Just a fractional turn of the knob above the surface of the oil near a hand hole opening—and the adjustment is made.

The principal advantages are:

1. Ease and safety of changing taps.
2. No waits for better weather or transformers to cool.
3. No loose parts to be accidently dropped into the windings.
4. No contacts that can be left loose.
5. Contacts are thorough and *positive*.
6. No diagrammatic sketches to be unravelled with possibility of errors.
7. Error proof. No open or short circuits by failure to make right connections.
8. Elimination of complicated and live terminal boards.

The Ratio Adjuster is an exclusive and original G-E development. Its merit has been established by five years of excellent service records. It is designed for the maximum possible conditions of service, i. e., full circuit current of the transformer and full line voltage between the tap leads.

The Adjuster is regularly supplied on standard distribution and small power transformers, sizes 50 to 500 Kv-a. above 6000 volts and 10 to 500 Kv-a., 13,200 volts and higher.

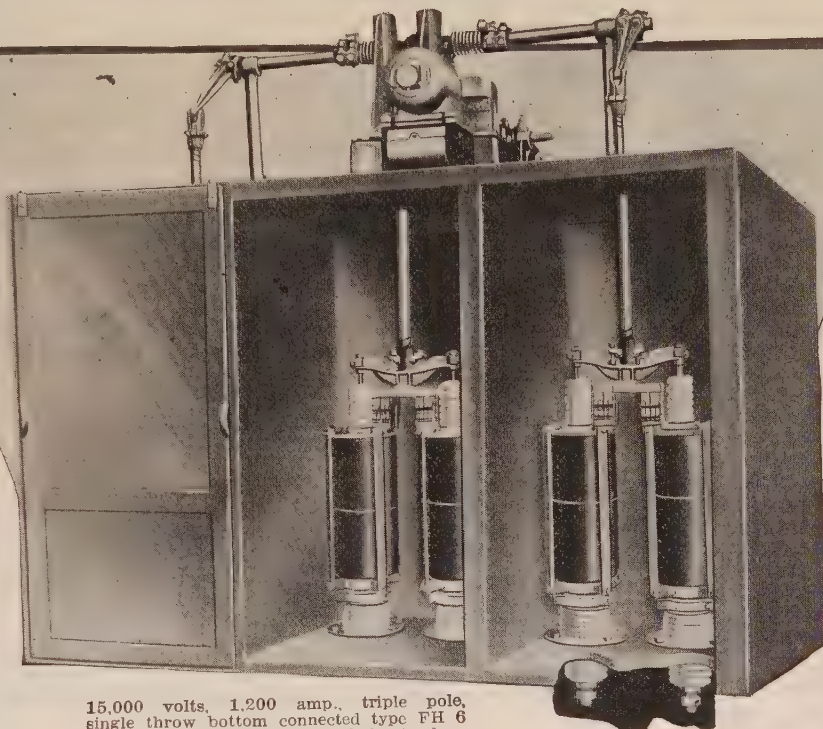
General Electric Company

General Office Schenectady, N.Y.

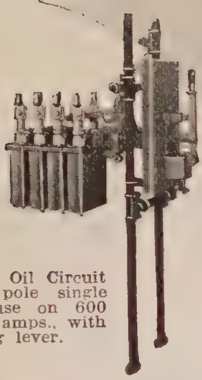
Sales Offices in all large cities

51-40

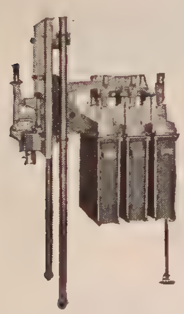
The safety of a transmission line's operators and equipment depends on the ability of its oil circuit breakers to clear disturbances



15,000 volts, 1,200 amp., triple pole, single throw bottom connected type FH 6 Oil Circuit Breaker, mounted in tandem.



Type FK 35 Oil Circuit Breaker, 4 pole single throw for use on 600 volts at 600 amps., with operating lever.



Type FK-32A Oil Circuit Breaker, triple pole, single throw, for use on 15,000 volts, 400 amp., with operating lever.

Type FK 52B Oil Circuit Breakers, triple pole, 25,000 volt, 800 amp., with automatic tripping attachment.

G-E Oil Circuit Breakers Have Met the Tests

The severe duties which oil circuit breakers are called upon to perform and the great losses which may result from a failure in operation, makes their selection of great importance and a matter which should always be given careful consideration.

G-E oil circuit breakers are available for the needs of all installations which are commercially feasible.

There is a G-E oil circuit breaker which has proved its fitness to meet the service requirements of each particular field.

G-E engineers are always available for consultation when oil circuit breaker problems are under consideration.

General Electric Company

General Office Schenectady, N.Y.

Sales Offices in all large cities

54A-36

THE MEN whose skill and experience select the materials and direct their fabrication into AMERICAN FIBRE CONDUIT have made fibre conduit since its earliest days of production.

This unique experience is the foundation of the high quality which has led to its wide use for UNDERGROUND ELECTRIC SYSTEMS.

American Fibre Conduit is of HOMOGENEOUS CONSTRUCTION, light, strong and compact.

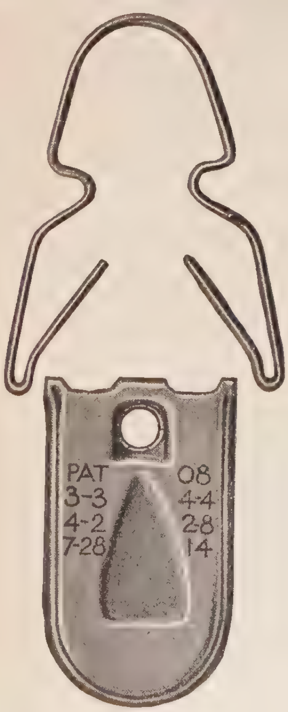
Large stocks of the two types of joint, the mortise and tenon or Socket Joint, and the tapered sleeve or "American" Harrington Joint, with Bends and Fittings make possible immediate shipments.

AMERICAN FIBRE CONDUIT is distributed throughout the United States by the 48 Distributing Houses of the

Western Electric Company
Offices in All Principal Cities

American Fibre Conduit Corporation

GENERAL SALES OFFICES
103 PARK AVE. AT 41st ST., NEW YORK, N. Y.
FACTORY: FULTON, N. Y.



METROPOLITAN

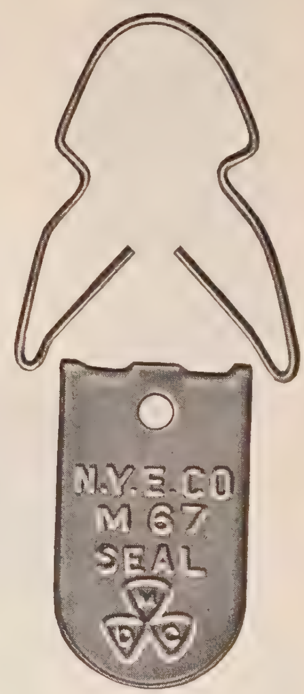
All=Metal Seals

GUARANTEE PROTECTION

No Sealing Tools Required

Let us tell you about them

Metropolitan Device Corporation
1250 Atlantic Avenue, Brooklyn, N. Y.



METROPOLITAN DEVICE CORPORATION
1250 Atlantic Ave., Brooklyn, N. Y.

Please send your latest data on All-Metal Seals. It is understood that this incurs no obligation.

Name of Company ....
By .... Title ....
Address ....
....
Date ....

Greetings:

A. I. E. E.

AT YOUR 1922 Annual Convention in Niagara Falls, Ontario, you will discuss the many varied problems of electrical engineering. It is a truism that accompanying most advances in electrical science and attendant on the majority of new applications of electricity,the question of the proper type transformer is usually present.

The particular function of the American Transformer Company and its technical staff is to design and build transformers made for individual purposes, beyond the limitations of ordinary commerical types. New applications of electrical energy to industrial processes demanding transformers of special design interest us particularly.

For years this Company has been building specialty type transformers. It has manufactured hundreds of transformers that are being used in almost as many kinds of industries. Superior results are obtained from AMERICAN TRANSFORMERS, because they are custom-made for the highest efficiency. AMERICAN TRANSFORMERS have an enviable reputation for operating economy and long life.

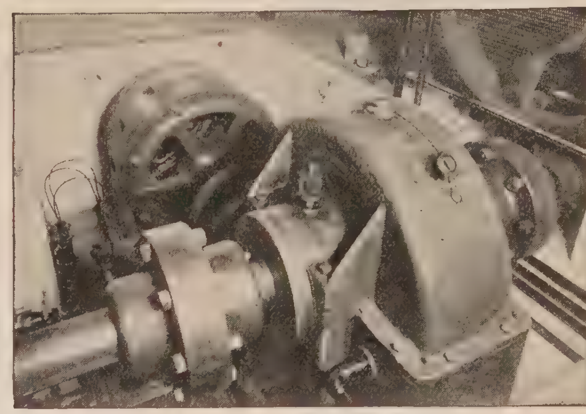
Electrical engineers and others are invited to confer or correspond with us on any transformer problem. Our specialized skill and knowledge—the result of years of study and experience—are at your service.

The American Transformer Company

176 Emmet Street, Newark, N. J.

AMERICAN TRANSFORMERS

Cleveland WORM GEAR REDUCTION UNITS



Cleveland Worm Gear Reduction Unit applied to mill line shaft, Motor 400 H.P.

No trouble—make it unanimous.

IF you as a buyer of speed reduction devices could only sit on our side of the desk for a few months you would be as enthusiastic as we are over Cleveland Worm Gear Reduction Units.

You would come in contact with the truth. You would read letters from America's greatest industrial concerns in many lines, you would talk to engineering firms who specialize on factory equipment; you would see letters from customers who have been using our speed reduction units for six and seven years and you couldn't help but come to the conclusion that we are making a wonderfully efficient and satisfactory device.

For the tone of all the letters and the frequency of repeat orders would evidence one outstanding fact—"no trouble".

Consider that we offer constant efficiency during entire life, even torque, freedom from vibration, compactness, simplicity, (only two moving parts aside from bearings) low maintenance cost, and ease of lubrication *plus* "no trouble", then write us your rquirements. Our engineering department is at your service.

The Cleveland Worm & Gear Co.

America's Worm Gear Specialists

CLEVELAND, OHIO

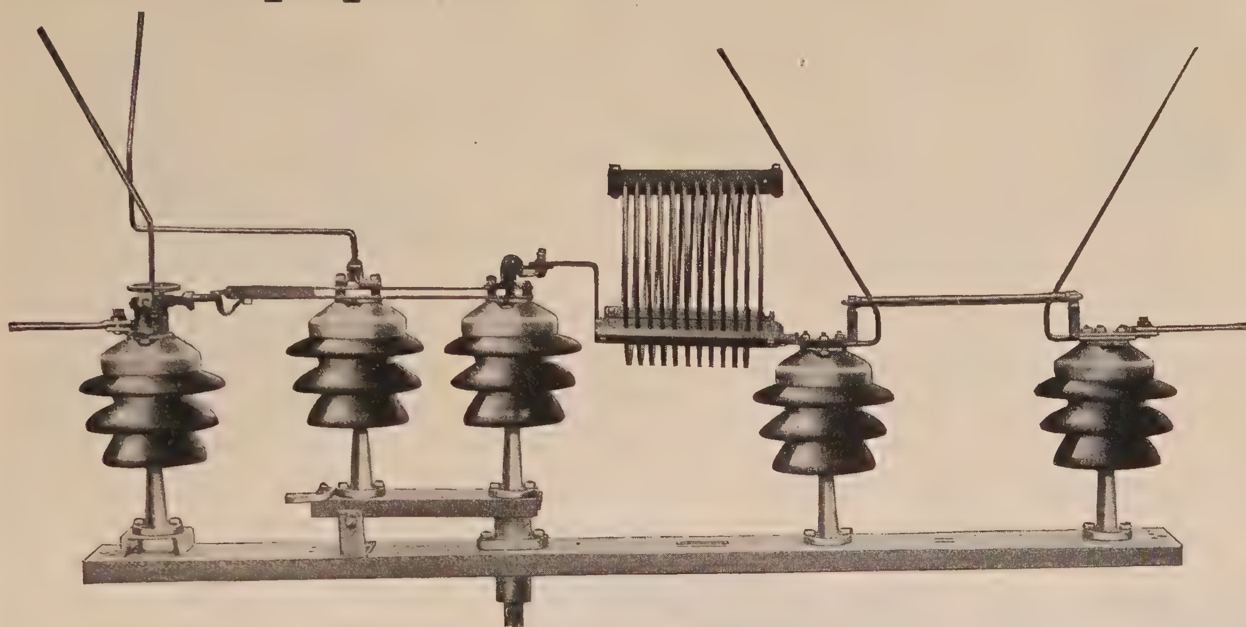
DRAVO-DOYLE CO., Pittsburgh
Cleveland, Indianapolis, Philadelphia

New England Representatives
FRANKLIN MACHINE CO., Providence, R. I.

Pacific Coast Representatives
ALFRED H. COATS CO., San Francisco, Cal.

Rocky Mountain States Representatives
THE VULCAN IRON WORKS CO., Denver, Colo.

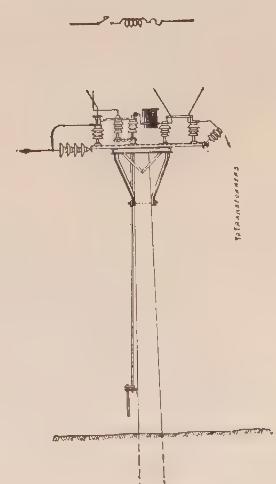
R. & I. E. Interchangeable Unit Equipment for Outdoor Service



Single Pole Unit, 37,000 volt, R. & I. E. Combination Horn Gap Switch, Cylindrical Choke Coil and Horn Gap Fuse.

RUGGED—INTERCHANGEABLE—ECONOMICAL—COMPACT

R. & I. E. designs, embodying INTERCHANGEABLE UNIT features are appreciated as representing the best that money can buy. ECONOMIZE—not by buying the cheapest, but by getting the utmost in value for money expended.



Our new bulletins are now being distributed.
Have you received yours?

RAILWAY AND INDUSTRIAL ENGINEERING COMPANY

GREENSBURG, PA.

TRANSMISSION SWITCHING AND PROTECTIVE — EQUIPMENT —

RAILWAY AND INDUSTRIAL ENGINEERING CO.

DISTRICT OFFICES:
PITTSBURGH NEW YORK
BOSTON CHICAGO
CINCINNATI

PROFESSIONAL ENGINEERING DIRECTORY

For Consultants in the Fields of Engineering, Architecture, Chemistry, Law, Physics, and Related Arts and Sciences

(Cards continued on next page.)

Classified Advertiser's Index for Buyers

A classified and comprehensive list of manufacturers and agents for machinery and supplies used in the electrical and allied industries; professional consultants and laboratories.

Note: For reference to the advertisements see the Alphabetical List of Advertisers on page 54.

AIR COMPRESSORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.

AIR WASHERS.
Spray Engineering Co., Boston

AMMETERS, VOLTMETERS.
(See INSTRUMENTS, ELECTRICAL)

ARMATURE WINDING APPARATUS.
Armature Coil Equipment Co., Cleveland.

BALANCING MACHINES, STATIC DYNAMIC
Olsen, Tinius, Testing Machine Co., Philadelphia

BATTERY CHARGING APPARATUS.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BEARINGS, BALL.
New Departure Mfg. Co., The, Bristol, Conn.
Norma Co. of America, L. I. City, N. Y.
S. K. F. Industries, New York.

BLOWERS, PORTABLE.
Emery & Sons, Chas. W., Philadelphia

BOXES, FUSE.
General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BOXES, JUNCTION.
G & W Elec. Specialty Co., Chicago.
Metropolitan Device Corp., Brooklyn, N. Y.

BRAKES, CAR.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.

BRUSHES, COMMUTATOR.
Carbon
Morganite Brush Co. Inc., New York.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Copper Graphite
Graphite Metallizing Corp., Yonkers, N. Y.
Morganite Brush Co. Inc., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BUS BAR FITTINGS.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BUSHINGS, LIGHT DUTY.
Graphite Metallizing Corp., Yonkers, N. Y.

CABLE ACCESSORIES.
Dossert & Co., New York
G & W Electric Specialty Co., Chicago, Ill.
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

CABLES.
(See WIRES AND CABLES)

CABLEWAYS.
Roebling's Sons Co., John A., Trenton, N. J.

CAMBRIC, VARNISHED.
Irvington Varnish & Ins. Co., Irvington, N. J.

CARBON BRUSHES.
(See BRUSHES, COMMUTATORS.)

CEDAR POLES.
Naugle Pole and Tie Co., Chicago
Page & Hill Co., Minneapolis, Minn.
Partridge Lumber Co., T. M., Minneapolis
Valentine-Clark Co., Minneapolis.

CIRCUIT BREAKERS.
Condit Electrical Mfg. Co., So. Boston, Mass.
Cutter Company, The, Philadelphia
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CLUTCHES, MAGNETIC.
Cutler-Hammer Mfg. Co., Milwaukee.

COIL WINDING APPARATUS.
Armature Coil Equipment Co., Cleveland.

COILS, MAGNET.
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago, Ill.
Dudlo Mfg. Co., Ft. Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONDENSER PACKING, METALLIC.
Crane Packing Co., Chicago

CONDENSERS.
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONDUIT, UNDERGROUND FIBRE.
American Fibre Conduit Corp., New York

CONNECTORS, SOLDERLESS.
Dossert & Co., New York, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONNECTORS AND TERMINALS.
Dossert & Co., New York
G & W Electric Specialty Co., Chicago, Ill.
Standard Underground Cable Co., Pittsburgh
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONTACTS, COPPER-GRAPHITE.
Graphite Metallizing Corp., Yonkers, N. Y.

CONTACTS, TUNGSTEN.
General Electric Co., Schenectady, N. Y.

CONTROLLERS.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Rowan Controller Co., Baltimore
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONVERTERS.
Allis-Chalmers Mfg. Co., Milwaukee
Northwestern Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

COOLING PONDS.
Spray Engineering Co., Boston

COPPER CLAD WIRE.
Copper Clad Steel Co., Rankin, Pa.
Standard Underground Cable Co., Pittsburgh

CUT-OUTS.
Condit Electrical Mfg. Co., So. Boston, Mass.
General Electric Co., Schenectady, N. Y.
G & W Elec. Spec. Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

DRAWING MATERIALS.
Keuffel & Esser, Hoboken, N. J.

DYNAMOS.
(See GENERATORS AND MOTORS.)

ELECTRIFICATION SUPPLIES, STEAM ROAD.
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, Ohio
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ENGINEERS, CONSULTING AND CONTRACTING.
(See PROFESSIONAL ENGINEERING DIRECTORY.)

ENGINES. *Gas & Gasoline.*
Allis-Chalmers Mfg. Co., Milwaukee
Oil
Allis-Chalmers Mfg. Co., Milwaukee
Steam
Allis-Chalmers Mfg. Co., Milwaukee

FANS, MOTOR.
Century Electric Co., St. Louis.
General Electric Co., Schenectady, N. Y.
Star Electric Motor Co., Newark, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FARM LIGHTING GENERATORS.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FIBRE.
Diamond State Fibre Co., Bridgeport, Pa.
National Fibre & Ins. Co., Yorklyn, Del.

FURNACES, ELECTRIC.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FUSES. *Enclosed Refillable*
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Enclosed Non-Refillable
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities
Open Link
General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
High Tension
Metropolitan Device Corp., Brooklyn, N. Y.
Railway & Industrial Engg. Co., Greensburg, Pa.

GEARS, FIBRE.
Diamond State Fibre Co., Bridgeport, Pa.
General Electric Co., Schenectady, N. Y.

GEARS, REDUCTION and HERRINGBONE.
Cleveland Worm & Gear Co., Cleveland

GENERATORS AND MOTORS.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Canadian General Elec. Co., Toronto, Ont.
Century Electric Co., St. Louis.
Electro-Dynamic Co., Bayonne, N. J.
General Electric Co., Schenectady, N. Y.
Northwestern Electric Co., Chicago
Star Electric Motor Co., Newark, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

GENERATING STATION EQUIPMENT.
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

GROUND RODS
Copper Clad Steel Co., Rankin, Pa.

HEADLIGHTS.
Ohio Brass Co., Mansfield, O.

HEATERS, INDUSTRIAL.
Cutler-Hammer Mfg. Co., Milwaukee.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

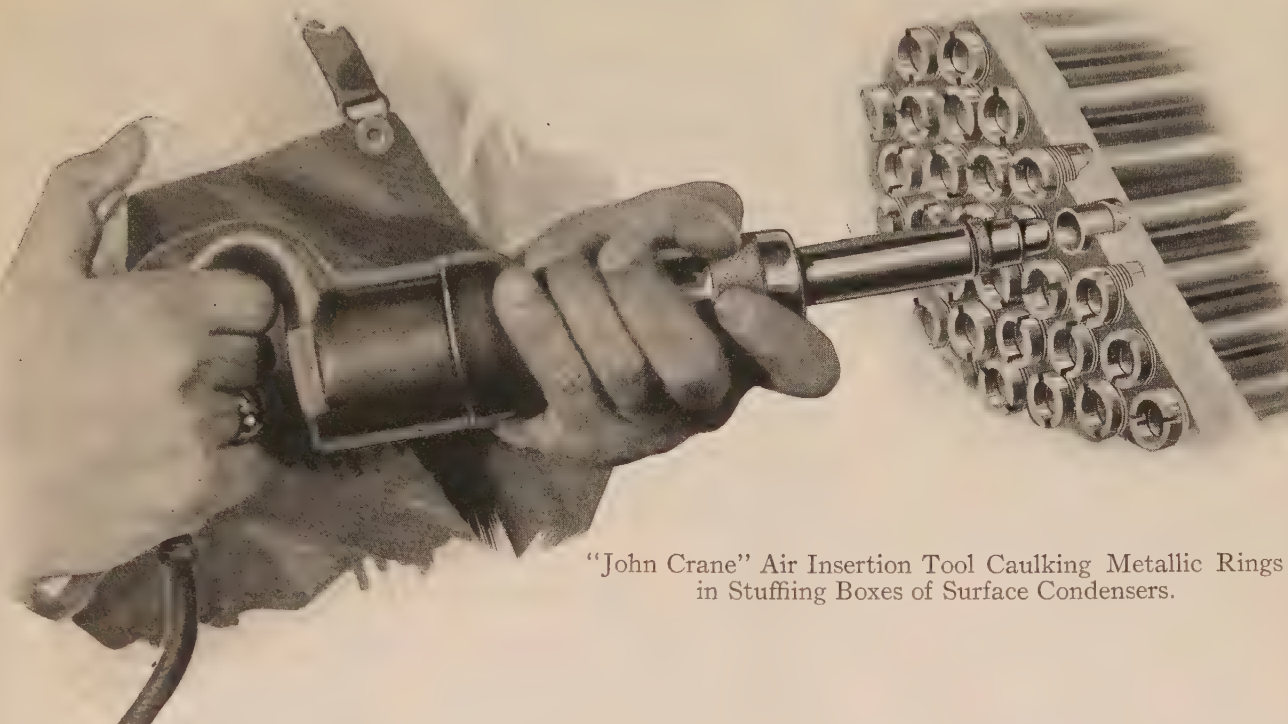
HYDROELECTRIC DEVELOPMENTS.
Cooper & Co., Hugh L., New York
Stone & Webster, Inc., Boston

INDICATORS, SPEED.
Biddle, James G., Philadelphia
Hasler-Tel Co., New York.
Roller-Smith Co., New York

INSTRUMENTS, ELECTRICAL.
Graphic
Biddle, James G., Philadelphia
Bristol Co., The, Waterbury, Conn.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Indicating
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Integrating
Biddle, James G., Philadelphia
Duncan Elec. Mfg. Co., Lafayette, Ind.
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
States Co., The, Hartford, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Repairing & Testing
Electrical Testing Laboratories, New York
National Elec. Inst. Co., Cambridge, Mass.
Scientific, Laboratory, Testing
Biddle, James G., Philadelphia
Cory & Son, Chas., Inc., New York
Foote, Pierson & Co., Inc., New York
General Electric Co., Schenectady, N. Y.
Leeds & Northrup Co., Philadelphia
Metropolitan Device Corp., Brooklyn, N. Y.
Roller-Smith Co., New York
States Co., The, Hartford, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Telegraph
Foote, Pierson & Co., Inc., New York
Western Electric Co., All Principal Cities
Wireless
Acme Apparatus Co., Cambridge, Mass.
General Radio Co., Cambridge, Mass.

INSULATING MATERIALS.
Cloth
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Composition
American Insulator Corp., New Freedom, Pa.
Belden Mfg. Co., Chicago
Cutler-Hammer Mfg. Co., Milwaukee.
Electrose Mfg. Co., Brooklyn, N. Y.
Redmanol Chemical Products Co., Chicago
Waterbury Button Co., Waterbury, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Compounds
Minerallac Electric Co., Chicago
Fibre
Diamond State Fibre Co., Bridgeport, Pa.
National Fibre & Ins. Co., Yorklyn, Del.
Lava
American Lava Co., Chattanooga, Tenn.
Paper
Irvington Varnish & Ins. Co., Irvington, N. J.
Silk
Irvington Varnish & Ins. Co., Irvington, N. J.

FLEXIBLE METALLIC PACKING



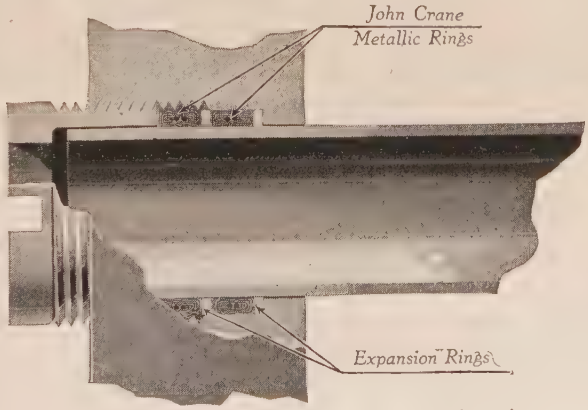
"John Crane" Air Insertion Tool Caulking Metallic Rings in Stuffiing Boxes of Surface Condensers.

Metallic Packing for Surface Condensers

The "John Crane" Process

ADVANTAGES

- It prevents leakage
- It maintains high vacuum
- Tube sheets are dry
- It is a permanent packing
- Steam cannot burn it out
- Cleaning chemicals do not affect it
- It is easy to install
- It prevents tube corrosion



Assembly of Metallic and Asbestos Rings in Stuffing Box

ADVANTAGES.

- It prevents gripping of tubes
- It eliminates electrolysis
- It saves replacement of tubes
- It allows the use of softer tubes
- It prevents cracking and splitting of tubes
- It cannot crush or deform tubes

This new metallic bonding method of packing surface condenser tubes is a decided step in advance of the old custom of using fabric packings, such as candle wicking, corset lacing and fibre washers which are insulators.

Write for our 26-page text-book on Corrosion and Disintegration of Condenser Tubes. It is free on application.

Crane Packing Company, 1804 Cuyler Ave. Chicago, Ill.

NEW YORK:	PHILADELPHIA	HOUSTON	CANADA:
710 Dodge Bldg.	108 Walnut Street	407 Scanlon Bldg.	Flexible Metallic Packing Co., Ltd., Windsor, Ont.

Classified Advertiser's Index for Buyers—*Continued.*

INSULATING MATERIALS—*Continued.*

Slate

Structural Slate Co., The, Pen Argyl, Pa.

Tape

Belden Mfg. Co., Chicago
Minerallac Electric Co., Chicago
Okonite Co., The, New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Varnishes

General Electric Co., Schenectady, N. Y.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago

INSULATOR TESTERS AND FAULT FINDERS.
Doble Engineering Co., Boston

INSULATORS, HIGH TENSION.

Composition

Electrose Mfg. Co., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.

Glass

Hemingray Glass Co., Muncie, Ind.

Porcelain

General Electric Co., Schenectady, N. Y.
Jeffrey-Dewitt Insulator Co., Kenova, W. Va
Locke Insulator Mfg. Co., Victor, N. Y.
Ohio Brass Co., Mansfield, O.
Thomas & Sons Co., R., East Liverpool, O.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

INSULATORS, TELEPHONE & TELEGRAPH
Hemingray Glass Co., Muncie, Ind.

LAMPS, ARC.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LAVA.
American Lava Co., Chattanooga, Tenn.

LINEMEN'S INSULATING SHIELDS.
Linemen Protector Co., Detroit

LINEMEN'S SHOES, INSULATED.
Linemen Protector Co., Detroit

LIGHTNING ARRESTERS.
General Electric Co., Schenectady, N. Y.
Railway & Industrial Engg. Co., Greensburg, Pa.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LOCOMOTIVES, ELECTRIC.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LUBRICANTS.
Texas Oil Co., New York

MAGNET WIRE.
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Dudlo Mfg. Co., Ft. Wayne, Ind.
Roebling's Sons Co., J. A., Trenton, N. J.
Rome Wire Co., Diamond Branch, Buffalo, N. Y.
Western Electric Co., All Principal Cities

METALLIC PACKING.
Crane Packing Co., Chicago

METERS, ELECTRICAL.
(See INSTRUMENTS, ELECTRICAL.)

METER LOADING DEVICES.
States Co., The, Hartford, Conn.

MOLDED INSULATION.
American Insulator Corp., New Freedom, Pa.
Belden Mfg. Co., Chicago
Cutler-Hammer Mfg. Co., Milwaukee.
Electrose Mfg. Co., Brooklyn, N. Y.
Redmanol Chemical Products Co., Chicago
Waterbury Button Co., Waterbury, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

MOTORS.
(See GENERATORS AND MOTORS.)

OHMMETERS.
Cory & Son, Chas., Inc., New York

PANEL BOARDS.
(See SWITCHBOARDS.)

PATENT ATTORNEYS.
(See PROFESSIONAL ENGINEERING DIRECTORY.)

PHASE MODIFYING APPARATUS.
States Co., The, Hartford, Conn.

PHOTOMETERS—SPHERES.
Foote, Pierson & Co., Inc., New York

PHOTOSTATS.
Photostat Corp., Rochester, N. Y.

PLUGS.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Hubbell, Inc., Harvey, Bridgeport, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

POLES, STEEL.
Archbold-Brady Co., Syracuse, N. Y.
Bates Expanded Steel Truss Co., Chicago

POLES—TIES, WOOD.
Naugle Pole & Tie Co., Chicago
Page & Hill Co., Minneapolis, Minn.
Partridge Lumber Co., T. M., Minneapolis
Valentine-Clark Co., Minneapolis, Minn.

POTHEADS.
G & W Electric Specialty Co., Chicago
Thoner & Martens, Boston

PROTECTIVE DEVICES.
Metropolitan Device Corp., Brooklyn, N. Y.

PULLEYS, PAPER.
Rockwood Mfg. Co., The, Indianapolis

PUMPS.
Allis-Chalmers Mfg. Co., Milwaukee
Goulds Mfg. Co., Seneca Falls, N. Y.

PYROMETERS.
Leeds & Northrup Co., Philadelphia

RADIO INSULATING PARTS.
Waterbury Button Co., Waterbury, Conn.

RADIO LABORATORY APPARATUS.
Acme Apparatus Co., Cambridge, Mass.
General Radio Co., Cambridge, Mass.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RAILWAY SUPPLIES, ELECTRIC
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RECTIFIERS.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

REGULATORS, VOLTAGE.
General Electric Co., Schenectady, N. Y.
States Co., The, Hartford, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RESISTANCE ELEMENTS.
Cutler-Hammer Mfg. Co., Milwaukee.
Wiegand Company, Edwin L., Pittsburgh

RHEOSTATS.
Cutler-Hammer Mfg. Co., Milwaukee.
Biddle, James G., Philadelphia, Pa.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ROPE, WIRE.
Roebling's Sons Co., John A., Trenton, N. J.

SEARCHLIGHTS.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SIGNALING SYSTEMS.
Cory & Son, Chas., Inc., New York

SLATE.
Structural Slate Co., The, Pen Argyl, Pa.

SOCKETS AND RECEPTACLES.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SOLENOIDS.
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Cutler-Hammer Mfg. Co., Milwaukee.
Dudlo Mfg. Co., Ft. Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SPEED REDUCERS.
Cleveland Worm & Gear Co., Cleveland

STOKERS, MECHANICAL.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SUB-STATIONS.
General Electric Co., Schenectady, N. Y.
Railway & Industrial Eng'g. Co., Greensburg, Pa.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHBOARDS.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Condit Electrical Mfg. Co., So. Boston, Mass.
General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHES.

Automatic Time

Cramer & Co., R. W., New York
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Disconnecting

Condit Elec. & Mfg. Co., So. Boston.
General Electric Co., Schenectady, N. Y.
K-P-F Elec. Co., San Francisco
Railway & Ind. Eng'g. Co., Greensburg, Pa.
Thoner & Martens, Boston

Fuse

General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston

Knife

Condit Elec. & Mfg. Co., So. Boston, Mass.
Cutter Company, The, Philadelphia.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Oil

Condit Elec. & Mfg. Co., So. Boston, Mass.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Remote Control

Condit Elec. & Mfg. Co., So. Boston
Cramer & Co., R. W., New York, N. Y.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Railway & Ind. Eng. Co., Greensburg, Pa.
Rowan Controller Co., Baltimore
South Bend Current Controller Co., South Bend, Ind.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TACHOMETERS.
Biddle, James G., Philadelphia
Hasler-Tel Company, New York

TELEGRAPH APPARATUS.
Foote, Pierson & Co., Inc., New York

TELEPHONE EQUIPMENT.
Western Electric Co., All Principal Cities

TESTING LABORATORIES.
Electrical Testing Labs., New York

TESTING MACHINES, BALANCE.
Olsen, Tinius, Testing Machine Co., Philadelphia

TOWERS, TRANSMISSION.
Archbold-Brady Co., Syracuse, N. Y.
Bates Expanded Steel Truss Co., Chicago

TRANSFORMERS.
Acme Apparatus Co., Cambridge, Mass.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
American Transformer Co., Newark, N. J.
Duncan Elec. Mfg. Co., Lafayette, Ind.
General Electric Co., Schenectady, N. Y.
Kuhlman Electric Co., Bay City, Mich.
Moloney Elec. Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Factory

American Transformer Co., Newark, N. J.
Kuhlman Electric Co., Bay City, Mich.
Moloney Elec. Co., St. Louis, Mo.
Pittsburgh Transformer Co., Pittsburgh

Furnace

Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Moloney Elec. Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh

Metering

American Transformer Co., Newark, N. J.
Pittsburgh Transformer Co., Pittsburgh, Pa.

Mill Type

Pittsburgh Transformer Co., Pittsburgh

Street Lighting

Kuhlman Electric Co., Bay City, Mich.

TROLLEY LINE MATERIALS.
Ohio Brass Co., Mansfield, O.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBINES, HYDRAULIC.
Allis-Chalmers Mfg. Co., Milwaukee
Cramp, Wm. & Sons, Ship & Eng. Bldg. Co., Philadelphia

Classified Advertiser's Index for Buyers—*Continued.*

ALPHABETICAL LIST OF ADVERTISERS

(For classified list of Advertisers see Pages 48, 50 and 52)

American Institute of Electrical Engineers

COMING MEETINGS

Annual Convention, Niagara Falls, Ontario, June 26-30.

Pacific Coast Convention, Vancouver, B. C., August 8-11.

MEETINGS OF OTHER SOCIETIES

American Assn. for the Advancement of Science, Salt Lake City, June 22-24.

American Electrochemical Society, Montreal, Sept. 21-23. Fall Meeting.

American Institute of Chemical Engineers, Niagara Falls, June 19-22. Summer Meeting

American Society of Civil Engineers, Portsmouth, N. H., June 21-22. Annual Convention.

American Society of Heating & Ventilating Engineers, Buffalo, N. Y., June 7-8; Detroit, Mich., June 9-10.

American Society for Testing Materials, Atlantic City, June 26-July 1. Annual Meeting.

Association of Iron and Steel Electrical Engrs., Cleveland, O., Sept. 11-15. Annual Convention.

Society of Automotive Engineers, White Sulphur Springs, June 20-24. Summer Meeting.

Society for the Promotion of Engineering Education, University of Illinois, June 20-23. Annual Convention.